SCIENCE FOR SOLUTIONS

NOAA COASTAL OCEAN PROGRAM
Decision Analysis Series No. 23, Volume 1

SCIENCE-BASED RESTORATION MONITORING OF COASTAL HABITATS

Volume One: A Framework for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000 (Public Law 160-457)

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OCTOBER 2003

U.S. DEPARTMENT OF COMMERCE
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Cover photo. A coastal wetland complex on the Lake Ontario shoreline. Photo courtesy of Doug Wilcox, United States Geological Survey.

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Note to Readers

Science-Based Restoration Monitoring of Coastal Habitats, Volume One: A Framework for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000 (Public Law 160-457), is a guidance manual that provides technical assistance, outlines necessary steps, and provides useful tools for the development and implementation of sound scientific monitoring of coastal restoration efforts. This document is a result of the Estuary Restoration Act (ERA), Title I of the Estuaries and Clean Waters Act of 2000. The National Oceanic and Atmospheric Administration (NOAA) was tasked with providing guidance for the development and implementation of restoration monitoring for projects funded under the Act. In addition to it's usefulness to restoration practitioners undertaking ERA projects, this document has broad application and will assist in the monitoring of coastal restoration projects regardless of their funding source.

The manual represents the first of a two volume series. This first volume contains a background on restoration and monitoring, stages of a restoration and monitoring plans, how to create a monitoring plan, and important information that should be considered when monitoring specific habitats. The second volume, to be published in 2004, provides detailed information on the habitats, an inventory of coastal restoration monitoring programs, a review of monitoring techniques manuals and quality control/quality assurance documents, an overview of governmental acts affiliated with monitoring, a cost analysis of monitoring expenses, a glossary of terms, and a discussion of socioeconomic issues affiliated with coastal habitat restoration.

The authors envision several possible outcomes that may result from this document. Improved and consistent restoration monitoring plans may be developed based on the standards this document presents. Restoration practitioners may more confidently conduct sound scientific monitoring of their coastal restoration efforts by utilizing the technical assistance and useful tools this document provides. In addition, this manual may allow restoration practitioners to detect early warnings that the restoration effort is not on track, to gauge how well a restoration site is functioning, to coordinate projects and efforts for consistent and successful restoration, and to evaluate the ecological health of specific coastal habitats both before and after project completion.

The National Centers for Coastal Ocean Science (NCCOS) provide a focal point through which NOAA, together with other organizations with responsibilities for the coastal environment and its resources, can make significant strides toward finding solutions to critical problems. By working together toward these solutions, we can ensure the sustainability of these coastal resources and allow for compatible economic development that will enhance the well-being of the Nation now and in future generations. The National Centers for Coastal Ocean Science thanks NOAA's Office of Response and Restoration and the Office of Habitat Conservation for their support in the creation of this document.

A specific objective of the NCCOS is to provide the highest quality scientific information to coastal managers in time for critical decision making and in formats useful form these decisions. To this end, the Decision Analysis Series was developed by the NCCOS Center for Sponsored Coastal Ocean Research, Coastal Ocean Program to synthesize information on issues of high priority to coastal managers. As a contribution to the Decision Analysis Series, this report provides a

critical synthesis of information need to successfully plan and execute a coastal habitat restoration monitoring plan. A list of available documents in the Decision Analysis Series can be found on the inside back cover.

As with all of its products, the NCCOS is very interested in ascertaining the utility of *Science-Based Restoration Monitoring of Coastal Habitats, Volume One: A Framework for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000*, particularly in regard to its application to the management decision process. Therefore, we encourage you to write, fax, call, or email us with your comments. Please be assured that we will appreciate these comments, either positive or negative, and that they will help us direct our future efforts. Our contact information is below.

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EXECUTIVE SUMMARY

The Estuary Restoration Act of 2000 (ERA), Title I of the Estuaries and Clean Waters Act of 2000, was created to promote the restoration of habitats along the coast of the United States (including the US protectorates and the Great Lakes). The NOAA National Centers for Coastal Ocean Science was charged with the development of a guidance manual for monitoring plans under this Act.

This guidance manual, titled *Science-Based Restoration Monitoring of Coastal Habitats*, is written in two volumes. It provides technical assistance, outlines necessary steps, and provides useful tools for the development and implementation of sound scientific monitoring of coastal restoration efforts. In addition, this manual offers a means to detect early warnings that the restoration is on track or not, to gauge how well a restoration site is functioning, to coordinate projects and efforts for consistent and successful restoration, and to evaluate the ecological health of specific coastal habitats both before and after project completion (Galatowitsch et al. 1998).

The following habitats have been selected for discussion in this manual: water column, rock bottom, coral reefs, oyster reefs, soft bottom, kelp and other macroalgae, rocky shoreline, soft shoreline, submerged aquatic vegetation, marshes, mangrove swamps, deepwater swamps, and riverine forests. The classification of habitats used in this document is generally based on that of Cowardin et al. (1979) in their Classification *of Wetlands and Deepwater Habitats of the United States*, as called for in the ERA Estuary Habitat Restoration Strategy.

This manual is not intended to be a restoration monitoring "cookbook" that provides templates of monitoring plans for specific habitats. The interdependence of a large number of site-specific factors causes habitat types to vary in physical and biological structure within and between regions and geographic locations (Kusler and Kentula 1990). Monitoring approaches used should be tailored to these differences. However, even with the diversity of habitats that may need to be restored and the extreme geographic range across which these habitats occur, there are consistent principles and approaches that form a common basis for effective monitoring.

Volume One, titled *A Framework for Monitoring Plans under the Estuaries and Clean Waters Act of 2000*, begins with definitions and background information. Topics such as restoration, restoration monitoring, estuaries, and the role of socioeconomics in restoration are discussed. In addition, the habitats selected for discussion in this manual are briefly described.

Volume One continues with a framework for developing a monitoring plan. The first element in this framework is an explanation of the stages of restoration and monitoring: project conception and design; monitoring plan development; data collection before, during, and after construction; and export of data. Second in this framework, the manual presents the process of developing a monitoring plan through twelve clear steps. These steps are 1) identify the goals of the project, 2) collect information on similar restoration monitoring projects, 3) identify and describe the habitats within the project area, 4) define basic structural and functional characteristics for those habitat types, 5) consult experts, 6) determine the hypotheses, 7) collect historical data, 8) identify reference sites, 9) identify monitoring time span, 10) identify monitoring techniques, 11) design a monitoring review and revision process, and 12) develop a cost estimate for implementation

of the monitoring plan. Third in this framework for developing a monitoring plan, the manual explains basic elements that should be considered when writing a restoration monitoring plan. These critical elements include background material, project goals and objectives, monitoring components (metrics, hypotheses, reference sites, pre-construction sampling plans, plans for sampling during and after construction, statistical analysis, data handling, report preparation, and review plans), projected budget, and participants' contact information. The manual also offers a series of three parameter matrices to help practitioners choose which habitat characteristics may be most appropriate to monitor for their project.

Volume Two, titled *Tools for Monitoring Coastal Habitats,* of the guidance manual *Science-Based Restoration Monitoring of Coastal Habitats* will follow the publication of Volume One in 2004. Volume Two will begin with detailed discussions of the habitats, including a description of the habitats, a review of restoration monitoring approaches applied within the habitats, common anthropogenic impacts on each habitat, and annotated bibliographies of monitoring projects, protocols, and techniques used in coastal habitat monitoring. Volume Two continues with a discussion on selection of reference sites or conditions, an inventory of monitoring programs in the United States, a review of acts relevant to restoration monitoring, a sample list of costs involved in restoration monitoring, and a review of socioeconomic factors associated with restoration monitoring.

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Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. United States Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Galatowitsch, S. M., A. G. van der Valk, and R. A. Budelsky. 1998. Decision-making for prairie wetland restorations. *Great Plains Research* 8: 137-155.

Kusler, J. A. and M. E. Kentula. 1990. Executive summary, pp. xvii-xxv. In J. A. Kusler and M. E. Kentula (eds.), Wetland Creation and Restoration: the Status of the Science. Island Press, Washington, D.C.

INTRODUCTION

This manual provides technical assistance in the development and implementation of sound scientific monitoring of coastal restoration efforts. It supports the maximization of societal and environmental benefits of coastal habitats throughout the estuaries and freshwater coastal ecosystems of the United States and its protectorates.

The document is not a restoration manual, nor does it develop specific monitoring plans. Instead, it outlines the steps necessary in the development of a scientifically sound and fiscally responsible restoration monitoring plan and provides tools to assist monitoring plan development and guide decision-making. This document provides practitioners with a scientifically sound and statistically valid basis and framework through which monitoring plans can be developed.

There are two volumes of this manual. In this first volume (*A Framework for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000*), readers will find a framework for the creation of a restoration monitoring program. The framework explains where monitoring fits into the restoration process, how to create a monitoring plan, and important information that should be considered when monitoring specific habitats.

The second volume (*Tools for Monitoring Coastal Habitats*) contains detailed discussions of the habitats including techniques manuals and quality control/quality assurance documents for monitoring in each habitat. Volume Two also includes an inventory of coastal restoration monitoring programs (including those in the Great Lakes region), an overview of Federal legislation associated with restoration monitoring, a cost analysis of monitoring expenses, and a discussion of socioeconomic issues associated with coastal habitat restoration. It will also provide readers with abundant references and contacts that can be pursued for further information on preparing a monitoring program.

The Audience – This manual is written for those involved in developing and implementing restoration monitoring plans, both scientists and non-scientists. This includes restoration professionals in academia and private industry, as well as those in Federal, state, local, and tribal governments. Volunteer groups, non-governmental organizations, environmental advocates, and individuals participating in restoration monitoring planning will also find this information valuable.

Why This Manual Was Written – The Estuary Restoration Act (ERA), Title I of the Estuaries and Clean Waters Act of 2000, was created to promote the restoration of coastal and estuarine habitats. Under the act, the National Oceanic and Atmospheric Administration (NOAA) is tasked with providing guidance for the development and implementation of monitoring for projects funded under the Act.

Within the tens of thousands of kilometers of United States coastline included under the ERA are diverse habitats, ranging from tropical coral reefs to temperate freshwater marshland to Arctic rocky shores. Even with the diversity of habitats that may need restoration and the extreme geographic range across which these habitats occur, there are consistent principles and approaches that form a common basis for effective restoration monitoring.

Figure 1. Red mangrove located along John Pennekamp State Park, Florida. Photo courtesy of Richard B. Mieremet, NOAA Office of Sustainable Development and Intergovernmental Affairs. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/coastline/line0013.htm

Without effective restoration monitoring, projects have several risks. It may be impossible to obtain early warnings indicating that a restoration project is not on track. The lack of monitoring makes it difficult to gauge how well a restoration site is functioning ecologically both before and after completion. In addition, the lack of monitoring may lead to poor project coordination. If multiple projects in the same watershed or ecosystem are not evaluated using a complementary set of protocols, a disjointed effort may produce a patchwork of restoration sites with varying degrees of success (Galatowitsch et al. 1998) and little means of comparing results or approaches among projects.

What This Manual Is – This manual is designed to outline the steps necessary to develop a scientifically sound and fiscally responsible restoration monitoring plan and to help identify the characteristics that restoration practitioners consider valuable indicators of a functioning habitat. It is not a restoration monitoring "cookbook" that provides templates of monitoring plans for specific habitats. The interdependence of a large number of site-specific factors does not allow a rigid approach in designing monitoring guidance with wide applicability (Kusler and Kentula 1990). Although consistent approaches and principles can be identified, specific monitoring methods will vary according to the goals of the project.

Why This Approach- Habitat types vary in physical structure and function within and between regions. Monitoring techniques used should be tailored to these differences. Even within a single habitat type, there are regional and geographic differences that make recommendation of one technique a useless exercise. For example, in the southeastern United States where tidal amplitude is moderate, an appropriate technique for assessing fish and invertebrate abundance in a restored

salt marsh is the use of a block net, fyke net, Breeder trap, or pit trap. However, in the Gulf of Mexico where marshes may remain flooded for long periods, none of these techniques may be appropriate. A drop sampler or pop net may be better. On the west coast where marsh systems tend to be small monoculture stands, it is often necessary to block the entire tidal inlet to assess faunal components. In other areas, beach seines are used. There are over a dozen techniques to measure fish and invertebrate presence, absence, or abundance. The scientific community varies greatly in the technique and monitoring design preferred.

Some historical databases and ongoing programs have well established sampling protocols that have been used for extended periods. Resource managers and scientists are often unwilling to change techniques for a restoration project because it would result in a decreased ability to compare data across the watershed and over time. Programs with strong investments in sampling protocols include the Southern California Coastal Water Research Project, Gulf of Maine Council Gulf Watch Program, Chesapeake Bay Monitoring Program, San Francisco Bay Conservation and Development Commission, Gulf of Alaska Ecosystem Monitoring and Research (GEM) program, Public Service Enterprise Group (PSEG) Estuary Enhancement Program, CALFED Bay Delta Program, and the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA). Techniques for evaluating a specific habitat characteristic vary among these programs and can even vary within a single program to accommodate local conditions. These programs address technical soundness in restoration monitoring protocols through a scientific advisory group that thoroughly reviews restoration monitoring plans.

The selection of sampling designs and statistical protocols are also influenced by local conditions. For example, the length of the growing season varies tremendously along the coastal United States. Restoration projects involving planting vegetation in the southeastern or Gulf regions are monitored on very different time schedules than projects constructed in higher latitudes. Additionally, statistical sampling designs will vary according to the structure of the habitats (e.g., stratified random sampling, line transects, and time series analysis). Landscape considerations such as patchiness and degree of channelization play a part in what sampling and statistical analysis techniques are used. One cannot dictate the timing of sampling or the way in which the data are analyzed without understanding the local conditions that comes through field evaluation.

Finally, a variety of available techniques exist for almost all metrics or characteristics recommended for evaluation. There is no one technique that fits all; each situation needs to be evaluated individually using the same approach in the restored as in the reference sites. It would be presumptive to recommend a single technique for a specific characteristic when scientists frequently do not agree among themselves on the most appropriate method to be used.

References

Galatowitsch, S.M., A.G. van der Valk, and R.A. Budelsky. 1998. Decision-making for prairie wetland restorations. *Great Plains Research* 8: 137-155.

Kusler, J. A. and M. E. Kentula. 1990. Executive summary, pp. xvii-xxv. In J. A. Kusler and M. E. Kentula (eds.), Wetland Creation and Restoration: the Status of the Science. Island Press, Washington, D.C.

BACKGROUND

What is Restoration?

The term *restoration* has a number of definitions, all of which share similar ideas. They often refer to the return of an area to a previous condition by improving the biological structure and function (NOAA 2002).

Some examples of definitions of restoration put forth by various authors and agencies are as follows:

- A putting or bringing back into a former, normal, or unimpaired state or condition (McKechnie 1983).
- A return from a disturbed or totally altered condition to a previously existing natural or altered condition by some action of man (Lewis 1990).
- Returning an ecosystem to a close approximation of its condition prior to disturbance (NRC 1992; Claw et al. 1998).
- Returning a degraded wetland or former wetland to a pre-existing condition or as close to that condition as is possible (NOAA 2002 online).
- The rehabilitation of wetlands that may be degraded or hydrologically altered; often involves reestablishing the vegetation (Mitsch and Gosselink 2000).
- The process of reestablishing a self-sustaining habitat that closely resembles a natural condition in terms of structure and function (NOAA 2002 online).
- The process of assisting the recovery and management of ecological integrity including a critical range of variability in biodiversity, ecological processes and structure, regional and historical context, and sustainable cultural practices (SER 2002).
- An attempt to reset the ecological clock and return a damaged ecosystem to its pre-disturbed state in structure and function (Cunningham et al. 1994).

The Society of Wetland Scientists (2000) defines wetland restoration as actions taken in a converted or degraded natural wetland that result in the reestablishment of ecological processes, functions, and biotic/abiotic linkages and lead to a persistent, resilient system integrated within its landscape. The Society believes that since the science of restoration is young, there is currently ambiguity in the use of the term. In an effort to develop a clear and consistent definition, they suggest five key elements necessary to define the concept effectively:

1. Restoration is the reinstatement of driving ecological processes.
2. Restoration should be integrated with the surrounding landscape.
3. The goal of wetland restoration is a persistent, resilient system.
4. Wetland restoration should result in the historic type of wetland but may not always result in the historic biological community and structure.
5. Restoration planning should include the development of structural and functional objectives and performance standards for measuring achievement of the objectives.

In this manual, restoration is defined as follows:

"*The process of reestablishing a self-sustaining habitat that in time can come to closely resemble a natural condition in terms of structure and function.*" -Turner and Streever 2002.

The definition of restoration used in this volume reinforces the definition of *estuary habitat restoration activity* that is defined in the ERA. Both call for the improvement of degraded habitat with the goal of reestablishing both structure and function integrated into the surrounding landscape.

Figure 2. Metzger Marsh on Lake Erie in 1994 before restoration. Photo courtesy of Doug Wilcox, United States Geological Survey. http://www.glsc.usgs.gov/science/wetlands/WilcoxWeb.htm.

Figure 3. Metzger Marsh on Lake Erie in 1996 after restoration. Photo courtesy of Doug Wilcox, United States Geological Survey. http://www.glsc.usgs.gov/science/wetlands/WilcoxWeb.htm.

Why Coastal Habitat Restoration?

Coastal habitats, including freshwater areas such as those associated with the Great Lakes, are among the most common habitats receiving restoration attention. Two hundred years ago there were 221 million acres (89.5 million hectares) of wetlands in the United States (Dahl 1990). Because of habitat destruction and replacement, only 105.5 million acres (42.7 million hectares) of wetlands remained in 1997 (Dahl 2001). Most destruction and alteration can be linked to population growth in coastal watersheds. Flooding, dredging, filling, construction, surface hardening, dam building, and sewage or other pollutant spilling have severely stressed many coastal habitats (Dahl 1990). Concerted attempts to restore damaged coastal ecosystems to a previous state have been ongoing since pollution became a major social and political issue in the 1960s (Alongi 1998).

Coastal habitats provide ecological, cultural, and economic value. They act as critical habitat for thousands of species by providing shelter, spawning grounds, and food. A high percentage of threatened and endangered species rely on these areas (Mitsch and Gosselink 2000). They act as buffers by filtering sediment and pollution from upland drainage to improve water quality, recharging aquifers, reducing the effects of floodwaters and storm surges, and preventing erosion. Coastal habitats provide cultural value to humans including recreation (boating, fishing, swimming, surfing, and bird watching), tribal subsistence, places of dwelling, scientific knowledge, and aesthetics. Tourism, commercial and recreational fisheries, and transportation are some examples of services coastal habitats provide that benefit the economy and provide goods to humans, both locally and nationally (EPA 1993). Because of their abundant values, coastal habitats should be managed carefully for the mutual benefit of all.

There are various categories of ecosystem stress, each of which can individually have a profound impact on restoration performance. Based on the recommendations of the Committee on Environment and Natural Resources Report on Ecological Forecasting (CENR 2001), NOAA has categorized environmental stressors under five headings:

Climate change can affect sea level, temperature, currents and water column stratification, precipitation, and storm frequency and intensity. In turn, these will impact freshwater inflows, sediment contribution to estuaries, and pollution.

Extreme natural events such as hurricanes, coastal storms, floods, and droughts produce environmental changes both directly and indirectly that can impact restoration project performance.

Pollution directly affects marine ecosystems and the performance of restoration. Non-point sources from agricultural and suburban runoff, and automobile and industrial air emissions have become stressors. Practitioners should be aware of how these could impact long-term performance of a restoration.

Invasive species can damage or replace native plants and animals. Resulting changes in community structure can impact the services and values that the restored habitat contributes to the coastal ecosystem. Invasive species have been a concern in many restoration projects on the east, west and Gulf coasts of the United States and coastal habitats of the Great Lakes. The common reed

(*Phragmites communis*), now considered native to the United States, is a rapid invader of coastal marshes, particularly where there has been disturbance. Australian pine (*Casuarina equisetifolia*) has invaded many mangrove habitats in Florida. Smooth cordgrass (*Spartina alterniflora*) has invaded shallow coastal areas along the west coast, converting sub-tidal to intertidal elevations and impairing shellfish bed growth. While these invasive species can provide habitat value, their presence at a restoration site should be considered counter to the goals established for a restoration project.

Land and resource changes result from increasing demands for food, fiber, and space. This frequently means loss or damage of natural habitats, increased water pollution, altered natural hydrology, and increased chemical and sediment runoff from land after storms. This is a major concern in restoration projects.

The performance of any restoration project should be placed in the context of interaction with other habitats relative to the landscape mosaic within which it is set (C. Simenstad, Univ. of WA, pers. comm.). While using the recommendations in this document, individuals and organizations should recognize that success of a coastal habitat restoration project or restoration of an entire estuary may largely depend on variables beyond the control of the project or program. This includes the quality of the water flowing into the estuary, which affects nutrient concentrations, light penetration, and sediment quality.

What is Restoration Monitoring?

The science of restoration requires two basic tools: the ability to manipulate ecosystems to recreate a desired community and the ability to evaluate whether the manipulations have produced the desired change (Keddy 2000). The latter is often referred to as restoration monitoring.

For this manual, the definition of restoration monitoring is as follows:

"The systematic collection and analysis of data that provides information useful for measuring project performance at a variety of scales (locally, regionally, and nationally), determining when modification of efforts is necessary, and building long-term public support for habitat protection and restoration."

There are several definitions of ecological monitoring:

- Repetitive measurements or observations recorded over time for the purpose of determining a condition or tracking change (Meeker et al. 1996).
- The systematic observation of parameters related to a specific problem, designed to provide information on the characteristics of the problem and their change with time (Nichols 1979).
- The consistent recording of data collected through standard methods, so that comparison can be made over time and across different sites (Washington et al. 2000).
- The systematic data collection that provides information on changes that can indicate problems and/or progress towards target criteria or performance standards, which, when met, indicated that established ecological goals have been reached (NOAA et al. 2002).

Figure 4. Volunteers transport salt marsh grass for planting along Eastern Neck Island, Maryland. Photo courtesy of NOAA Restoration Center. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/habrest/r0006505.htm

Figure 5. Pam Polmateer prepares to take a secchi disk depth reading in the Puget Sound near Seattle, Washington. Photo courtesy of Felicity Burrows, NOAA National Centers for Coastal and Ocean Science.

Restoration Monitoring in Coastal Habitats – Restoration monitoring contributes to the understanding of complex ecological systems (Meeker et al. 1996) and is essential in documenting restoration performance and adapting project and program approaches. For example, monitoring coastal areas can identify opportunities for ecological enhancement (Good 2002), provide indications of ecosystem condition, warn of environmental decline (Washington et al. 2000), establish a record of conditions or trends, track conditions through a storm or unique event (EPA 1993), and identify gaps in existing scientific knowledge (Kusler and Kentula 1990). Additionally, thorough restoration monitoring provides the basis for a rigorous review of the pre-construction project planning and engineering. This allows for design improvement and evaluation of future projects, both of which will eventually lead to more efficient restoration monitoring.

Restoration monitoring can provide important information for future, current, or completed projects. Monitoring restored coastal areas can provide tools for planning management strategies and help improve

future restoration practices and projects (Washington et al. 2000). It can be used to determine whether project goals are being met and if mid-course corrections are necessary. Monitoring provides information on whether selected project goals are good measures for future projects and on how to do routine maintenance in a restored area (NOAA et al. 2002).

Currently, there is an abundance of coastal habitat ecological monitoring programs across all coastal states, including the Great Lakes. These programs, primarily ecological monitoring rather than strictly restoration monitoring, vary in size and scope and can often be divided into two categories: basic and extensive monitoring. Basic monitoring involves collection of information such as vegetative cover, water quality, and observations on aquatic life in coastal areas. This sort of monitoring can provide an important connection between restoration ecologists and the community. Basic coastal monitoring projects often rely on trained volunteers for much of the data collection. Volunteer opportunities in monitoring allow citizens and students to learn about the coastal environment in a hands-on manner (Washington et al. 2000). More extensive monitoring often involves the collection of data using more specialized methods and equipment. Examples of data collected from extensive monitoring in coastal areas include sedimentation rates, sediment chemistry, plant biomass, and food and habitat preferences (Good 2002).

What is the Role of Socioeconomics in Restoration?

It is becoming increasingly evident that decisions regarding restoration cannot be made solely by using ecological metrics but should involve social and economic considerations and measurements of success, as well. Local communities have a vested interest in coastal restoration and are directly impacted by the outcome of restoration projects in terms of aesthetics, economics, or culture. Socioeconomic metrics, whether currently available or yet to be developed, should reflect societal uses of the resource to be restored. Establishing these types of metrics will increase the public's understanding of the potential benefits of a restoration project and will increase public support for restoration activities.

Figure 6. Bureau of Commercial Fisheries Research Vessel CISCO returning to port on Great Lakes. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/ships/ship0361.htm

Consideration of socioeconomic issues is not a standard part of the coastal restoration process. Most restoration programs do not integrate social or economic factors into restoration monitoring and few restoration projects have implemented full-scale socioeconomic monitoring. Some restoration plans are developed in an institutional setting that require more deliberate consideration of socioeconomic impacts and goals, although this does not generally extend to the monitoring stage. Linking socioeconomic monitoring metrics with specific

habitat types is problematic given the limited use of socioeconomic monitoring and the diversity of habitat types frequently addressed by individual restoration projects.

As with evaluating the ecological effects of a restoration project, several steps should be taken in the restoration process in order to develop appropriate socioeconomic goals and metrics. The process of establishing monitoring metrics should be open to stakeholder involvement and should yield monitoring metrics that stakeholders care about and understand. The structure of stakeholder involvement could take several directions. For small to medium sized projects, restoration managers may want to consider an expert panel approach comprised of, for example, scientists, economists and sociologists as well as local representatives. For larger or more complex efforts, managers should consider a more extensive public involvement process. Monitoring metrics should be selected systematically. Planners should clearly establish the socioeconomic goals of the project through collaborative group discussion. Metrics should be generated that could be used to monitor progress against the stated goals. These metrics should be made an integral part of the restoration project's monitoring plan. Adaptive management strategies should be used and should involve the members of the local community and user groups in interpreting and responding to the results of socioeconomic monitoring.

What is an Estuary?

Estuaries are vital components of coastal regions. Marine, estuarine and Great Lakes coastal systems of the United States directly or indirectly support some of the nation's most profitable recreational and commercial fisheries, as well as providing habitat, food sources, and resting places for numerous endangered and ecologically important species.

Figure 7. Recreational fishing off the jetty at Panama City Beach. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/fish/fish1196.htm

For this manual, an estuary is operationally defined as follows[1]:

"An estuary is a part of a river, stream, or other body of water that has at least a seasonal connection with the open sea or Great Lakes and where the seawater or Great Lakes water mixes with the surface or subsurface water flow, regardless of the presence of man-made structures or obstructions."

This definition includes both freshwater and estuarine habitats within the following boundaries:

- Marine coastal habitats extending from the head of tide downstream to nearshore terminus structures, such as barrier islands, reefs, sand bars, mudflats, and headlands in close proximity to the connection with the open sea.

[1] *The definition of the term estuary and the habitat boundaries are taken from the text of the Estuary Restoration Act of 2000 and the ERA Estuary Habitat Restoration Strategy (Federal Register, Volume 67, Number 232, December 3, 2002, pages 71942-71949).*

- Great Lakes habitats: riparian and nearshore areas adjacent to the drowned mouths of streams entering the Lakes. Operationally, the landward boundary reaches to the 100-year flood line of the Great Lakes.

Figure 8. Floodwood Pond in Jefferson County, New York along the Lake Ontario shoreline is a good example of a coastal wetland formed behind a protective barrier beach. Photo courtesy of Doug Wilcox, United States Geological Survey.

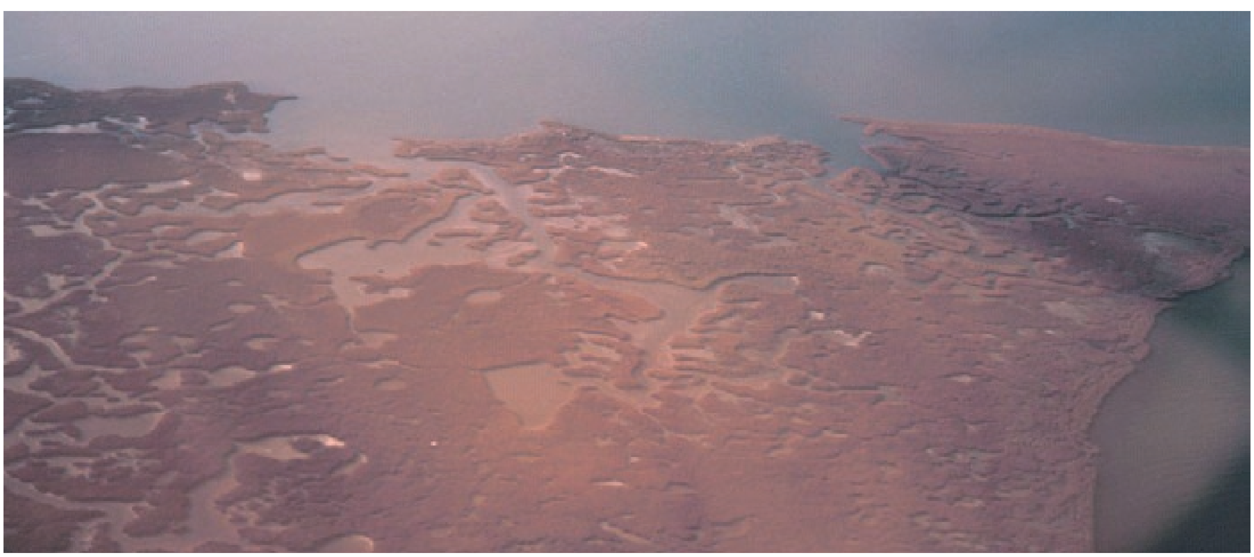

Figure 9. Aerial photograph of marsh land in Barataria Basin, Louisiana. Photo courtesy of Terry McTigue, NOAA Office of Response and Restoration. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/coastline/line1260.htm

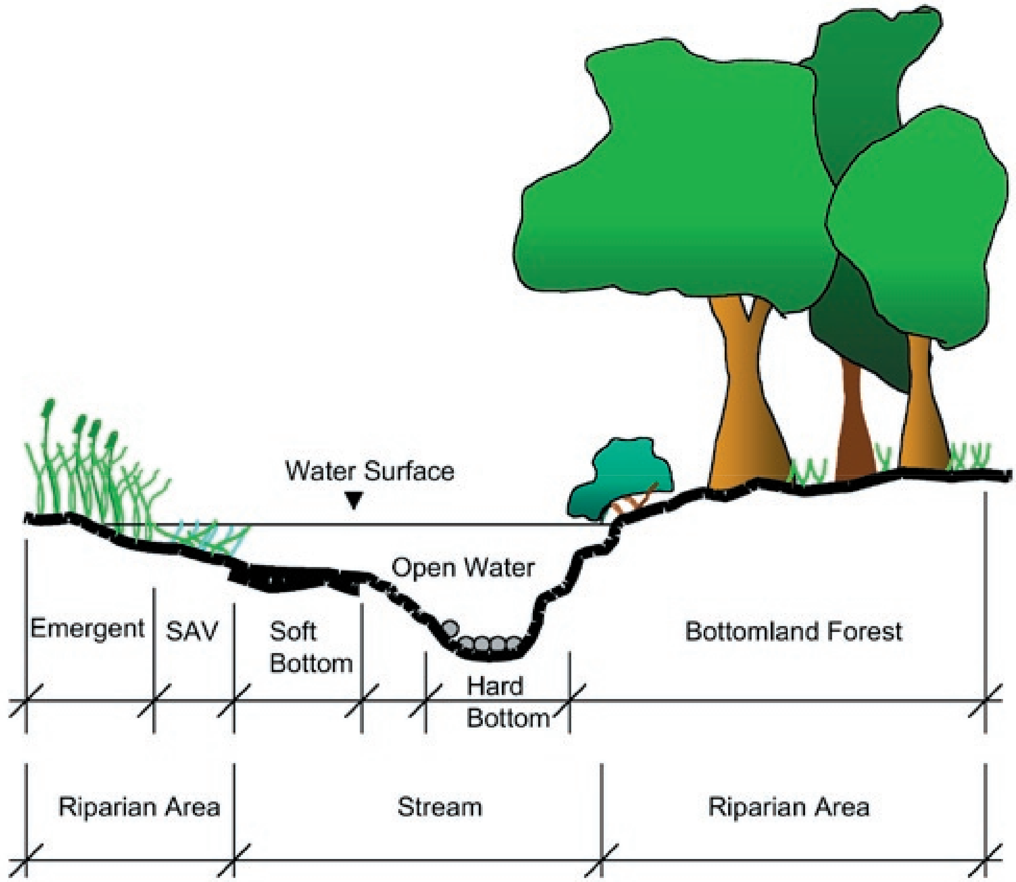

Figure 10. An idealized cross-section of a stream and riparian area, illustrating the diversity of specific habitat types that can occur within those general categories. To use this document for developing a monitoring plan for a stream-side riparian area restoration, the necessary information will be found in the different habitats present in a riparian area. In this example: Riverine Forest, Marsh, and SAV. SAV = submerged aquatic vegetation. Illustration by David Merkey, NOAA Great Lakes Environmental Research Lab.

What are the Habitats?

The number and types of habitats available in any given estuary are a product of a complex mixture of the local physical and hydrological characteristics of the water body and the organisms living there. Some examples include salt and freshwater coastal marshes, coastal forested wetlands, tidal flats, shellfish beds, seagrass meadows, kelp beds, and rocky and soft shorelines. The Cowardin et al. (1979) classification system[2], a national standard for wetland mapping, monitoring, and data reporting, contains 64 different categories of estuarine and tidally-influenced habitats that could be eligible for restoration under the ERA. Add this to local and regional differences in habitat

[2]*The Strategy to implement the ERA states: "the Council will use a classification system based on Cowardin et al. (1979). The Cowardin classification system is the national standard for wetland mapping, monitoring and data reporting as determined by the Federal Geographic Data Committee (http://www.fgdc.gov/). Examples of the relevant classes are: Estuarine subtidal, including open water, bay bottoms, and reefs; estuarine intertidal emergents, such as salt marsh; estuarine intertidal forested/shrub, such as mangroves; estuarine intertidal unconsolidated shore, such as beaches, bars and mudflats; and estuarine aquatic bed, such as submerged or floating estuarine vegetation. Freshwater habitat categories to be included because they are estuarine-associated ecosystems or are found in the Great Lakes include: palustrine forested wetlands, such as forested swamps or riparian zones; palustrine shrub wetlands; and palustrine emergents, including inland marshes and wet meadows."*

definitions and terminology and the list of habitat types continues to grow. It would therefore be impractical to provide a list of specific structural and functional characteristics to monitor during restoration projects for each and every local or regional habitat type.

In light of this, the habitat types presented in this document should be numerically small, broad in scope, and flexible in definition. Restoration practitioners should consider local conditions and pick and choose which general habitat types are present and which monitoring measures might apply. A restoration project may focus on one particular habitat type or may contain a number of habitat types. For example, a project may attempt to restore an area of emergent marsh only or it may attempt a more complex restoration of a tidal stream and its associated riparian zones. These areas may be made up of emergent marsh, submerged aquatic vegetation (SAV), soft bottom, rock bottom, open water, and riverine forest habitats. Figure 1 shows this complex habitat combination. If one were considering restoring the stream area itself, open water, soft bottom, and hard bottom habitats would need to be considered. For riparian areas, riverine forest, emergent marsh, and SAV should be included in consideration for monitoring in this example. Project areas can be diverse. Restoration practitioners should expect to regularly work in areas containing multiple habitat types.

The classification of habitats used in this document is generally based on that of Cowardin et al. (1979) in their *Classification of Wetlands and Deepwater Habitats of the United States*, as called for in the ERA Estuary Habitat Restoration Strategy[3]. The terms "riparian" and "stream" are geographic designations that can include multiple habitats. As illustrated in Figure 1, a riparian area may include SAV, marsh, and riverine forest habitats. Additionally, "palustrine forested wetlands" are included in the ERA Strategy as a freshwater category. Similarly, forested wetlands are actually a group of related habitats and will be treated as several separate habitats.

What is the Habitat Decision Tree?

A habitat decision tree has been constructed to assist in the easy differentiation among the habitats included in this framework. The tree allows readers to overcome the restraints of varying habitat related terminology in deciding which habitat definitions best describe the habitats within their project area.

In many cases, a project area will contain more than one habitat type. To appropriately determine the habitats within a project area, the practitioner should gather surveys and aerial photographs of the project area. From this information, he or she will be able to break down the project area into a number of smaller areas that share basic structural characteristics. The practitioner should then work through the habitat decision tree for each of these smaller areas. For example, a practitioner working in a riparian area may find a project area contains riverine forest, rocky shoreline, and rock bottom. Similarly, someone working to restore an area associated with a tidal creek or stream may find the project area contains water column, marshes, soft shoreline, soft bottom, and oyster reefs.

Once determination of habitat types within the project area has been made, the practitioner should address the appropriate monitoring of each of those habitats. Brief habitat definitions

[3]The ERA Estuary Habitat Restoration Strategy (Federal Register, Volume 67, Number 232, December 3, 2002, pages 71942 - 71949) states: "The Council will use a classification based on Cowardin et al., 1979. The Cowardin classification system is a national standard for wetland mapping, monitoring, and data reporting…"

are provided after the habitat decision tree and a general description for each can be found in Appendix I. Identification of structural and functional characteristics of the habitats, identification of parameters that determine the status of those habitat characteristics, and determination of the potential parameters for use in each habitat are presented in three matrices in Appendix II. Detailed descriptions and explanations of the importance of each of the structural/functional characteristics and suggested restoration monitoring measures are presented in *Volume Two: Tools for Monitoring Coastal Habitats*.

Habitat Decision Tree

1. a. Habitat consists of open water and does not include substrate (Water Column)
   b. Habitat includes substrate (go to 2)
2. a. Habitat is continually submerged under most conditions (go to 3)
   b. Habitat substrate is exposed to air as a regular part of its hydroperiod (go to 8)
3. a. Habitat is largely unvegetated (go to 4)
   b. Habitat is dominated by vegetation (go to 7)
4. a. Substrate is composed primarily of hard materials, either of biological or geological origin (go to 5)
   b. Substrate is composed primarily of soft materials, such as mud, silt, sand, or clay (Soft Bottom)
5. a. Substrate is composed of geologic material, such as boulders, bedrock outcrops, gravel, or cobble (Rock Bottom)
   b. Substrate is biological in origin (go to 6)
6. a. Substrate was build primarily by oysters, such as *Crassostrea virginica* (Oyster Reefs)
   b. Substrate was build primarily by corals (Coral Reefs)
7. a. Habitat is dominated by macroalgae (Kelp and Other Macroalgae)
   b. Habitat is dominated by rooted vascular plants (SAV)
8. a. Habitat is not predominantly vegetated (go to 9).
   b. Habitat is dominated by vegetation (go to 10)
9. a. Substrate is hard, made up materials such as bedrock outcrops, boulders, and cobble (Rocky Shoreline)
   b. Substrate is soft, made up of materials such as sand or mud (Soft Shoreline)
10. a. Habitat is dominated by herbaceous, emergent, vascular plants. The water table is at or near the surface or the area is shallowly flooded (Marshes)
    b. Habitat is dominated by woody plants (go to 11)
11. a. The dominant woody plants present are mangroves, including the genera *Avicennia*, *Rhizophora*, and *Laguncularia* (Mangrove Swamps)
    b. The dominant woody plants are other than mangroves (go to 12)
12. a. Forested habitat experiencing prolonged flooding, such as in areas along lakes, rivers, and in large coastal wetland complexes. Typical dominant vegetation includes bald cypress (*Taxodium distichum*), black gum (*Nyssa sylvatica*), and water tupelo (*Nyssa aquatica*). (Deepwater Swamps)
    b. Forested habitat along streams and in floodplains that do not experience prolonged flooding (Riverine Forests)

Habitat Definitions

Water column – A conceptual volume of water extending from the water surface down to, but not including the substrate. It is found in marine, estuarine, river, and lacustrine systems.

Rock bottom - Includes all wetlands and deepwater habitats with substrates having an areal cover of stones, boulders, or bedrock 75% or greater and vegetative cover of less than 30% (Cowardin et al. 1979). Water regimes are restricted to subtidal, permanently flooded, intermittently exposed, and semi-permanently flooded. The rock bottom habitats addressed include bedrock and rubble.

Coral reefs – Highly diverse ecosystems, found in warm, clear, shallow waters of tropical oceans worldwide. They are composed of marine polyps that secrete a hard calcium carbonate skeleton, which serves as a base or substrate for the colony.

Oyster reefs – Dense, highly structured communities of individual oysters growing on the shells of dead oysters.

Soft bottom – Loose, unconsolidated substrate characterized by fine to coarse-grained sediment.

Kelp and other macroalgae – Relatively shallow (less than 50 m deep) subtidal algal communities dominated by very large brown algae. Kelp and other macroalgae grow on hard or consolidated substrates forming extensive three-dimensional structures that support numerous flora and fauna assemblages.

Rocky shoreline – Extensive littoral habitats on high energy coasts (i.e. waves or ice).

Soft shoreline – Unconsolidated shore includes all wetland habitats having three characteristics: (1) unconsolidated substrates with less than 75% areal cover of stones, boulders, or bedrock; (2) less than 30% areal cover of vegetation other than pioneering plants; and (3) any of the following water regimes: irregularly exposed, regularly flooded, irregularly flooded, seasonally flooded, temporarily flooded, intermittently flooded, saturated, or artificially flooded (Cowardin et al. 1979). This definition includes cobble-gravel, sand and mud. However for the purpose of this document, cobble-gravel will not be addressed.

Submerged aquatic vegetation (SAV; marine/brackish and freshwater) – Seagrasses and other rooted aquatic plants growing on soft sediments in sheltered shallow waters of estuaries, bays, lagoons, and lakes. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Marshes (marine/brackish and freshwater) – Transitional habitats between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water tidally or seasonally. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Mangrove swamps – Swamps dominated by shrubs that live between the sea and the land in areas that are inundated by tides. Mangroves thrive along protected shores with fine-grained sediments where the mean temperature during the coldest month is greater than 20º C, which limits their northern distribution.

Deepwater swamps – Forested wetlands that develop along edges of lakes, alluvial river swamps, in slow-flowing strands, and in large coastal-wetland complexes. They can be found along the Atlantic and Gulf Coasts and throughout the Mississippi River valley. They are distinguished from other forested habitats by the tolerance of the dominant vegetation to prolonged flooding.

Riverine forests – Forests found along sluggish streams, drainage depressions, and in large alluvial floodplains. Although associated with deepwater swamps in the southeastern United States, riverine forests are found throughout the United States in areas that do not have prolonged flooding.

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DEVELOPING A MONITORING PLAN

Stages of Monitoring and Restoration

Monitoring is an integral part of the restoration process. Aspects of restoration monitoring should be considered throughout project design, construction, and implementation (Figure 2). Accurate gauging of the function of a restoration project is crucial not only to effective adaptive management of the project, but also to the success of future projects.

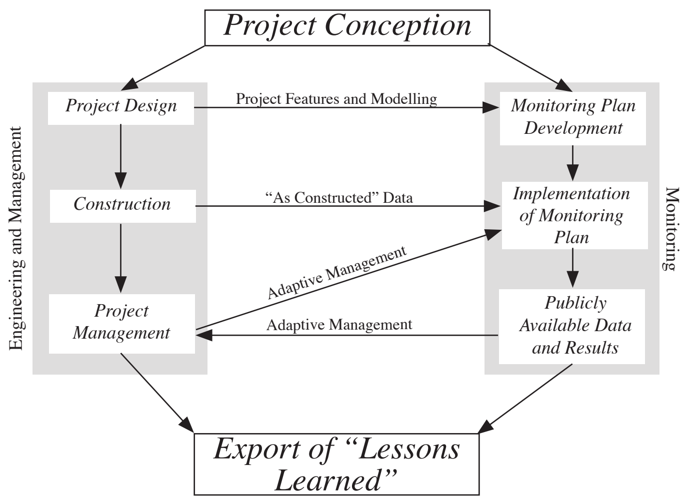

Figure 11. A flow diagram representing the process of developing, constructing, monitoring, and managing a coastal restoration project. The interaction of monitoring with other aspects of the process is emphasized. Illustration by Teresa McTigue, NOAA National Centers for Coastal Ocean Science.

Project Conception — Establish clearly defined project goals, objectives, and success criteria for a restoration project. These should be established not only on the basis of good science, but also on the goals and values of the local communities. These goals and objectives form the basis of the restoration monitoring plan. Before construction commences, it is necessary to establish how progress toward these goals and objectives will be measured.

Monitoring Plan Development — A restoration monitoring plan needs to be developed well before construction begins, as early as during the project design process. The steps for developing a monitoring plan are outlined in the following section of this document. Several important considerations should be made in the development of a monitoring plan. These include considering the impact of monitoring on the habitat, the selection of useful and appropriate reference sites, collecting baseline data, and the establishment of testable hypotheses.

In developing a restoration monitoring plan it is important to consider how to minimize the impact monitoring has on the habitat. For example, non-destructive sampling is recommended wherever and whenever possible. In addition, arrangements should be made for the clean up and removal of materials and equipment used to collect data. Materials (such as rebar) should never be left in the field upon completion of a monitoring project.

Reference sites against which the project area will be compared need to be identified. These sites can be of two forms: sites that possess attributes similar to the proposed restoration site and sites representing the condition to which the project area should optimally be restored. The type of reference site used depends on the goals of the restoration project and the availability of potential sites in the area. Multiple reference sites are highly recommended.

Comprehensive surveys of the project area and reference sites should be conducted to establish baseline environmental data. Information should also be obtained through analyses of archival materials and historical databases, when available. Field sampling and surveys should be done to address gaps in knowledge and to check the veracity of archival information. Modeling may be necessary, depending on the project in question. In obtaining baseline measurements, restoration practitioners should, depending on habitat type and surrounding conditions, consider characterizing and identifying species distribution and abundance; identifying habitats critical to resources of concern; calculating sediment budgets; determining local hydrographic regimes (including tidal and elevation data); document presence of invasive species and contaminants, and predicting possible changes in water quality and channel morphology. It also is important to identify watershed input-related problems that may impact not only the success of restoration within the estuary, but also the restoration practitioners' ability to develop appropriate water quality parameters. This descriptive information is critical to the development of the restoration monitoring plan.

Habitat characteristics to be monitored should be determined based on the goals for the project. It is important that the restoration monitoring plan establish testable hypotheses for each restoration goal. For each set of hypotheses, the plan should address data collection, recording, and analysis procedures. Valid statistical sampling and analyses should be established for each habitat characteristic to be monitored. Metadata should be reported in a format compatible with the NOAA ERA database. Timing of sampling should also be considered. Structural characteristics of the restored area should be monitored at the greatest frequency for several years immediately after construction. Functional characteristics[4], however, should be monitored later, as the system matures and the function in question has had time to become adequately established.

Implementation of Monitoring Plan — The three phases a practitioner progresses through when implementing a monitoring plan are pre-construction monitoring, monitoring during construction, and post-construction monitoring.

> *Pre-construction monitoring* — It is critical to begin monitoring both the project area and reference sites well before project construction begins. Pre-construction monitoring coupled with information used in the characterization of the site will give an indication of the current variability in a parameter. This variability can be related to short-term events, such as storms, or can result from seasonal or inter-annual patterns. While it is often difficult for those involved with monitoring to influence the construction schedule for a project, a pre-construction sampling period of at least a year is highly recommended. This monitoring should be conducted according to the restoration monitoring plan and the data should be collected and analyzed in a statistically valid manner. Pre-construction data and results should be made available to project engineers and managers to help them in the design, implementation, and scheduling of the project.
>
> *Monitoring during construction* — Upon completion of baseline data collection and restoration monitoring plan development, restoration construction can commence according to project design and specifications. Monitoring should be implemented during construction to ensure that proper design specifications are met.

[4]*Structural and functional characteristics for each habitat type are listed in Appendix I of this volume and receive extensive treatment within Volume Two: Tools for Monitoring Coastal Habitats*

Post-construction monitoring — Post-construction monitoring should be done according to the restoration monitoring plan, including the collection and analysis of data in a statistically valid manner. Data should be made available to project managers and engineers in a timely manner, as per the monitoring plan, to allow for adaptive management of the restoration project and associated programs.

Measuring progress in the development of habitat characteristics and associated community structure as well as working toward habitat stability and desired ecological and socioeconomic endpoints is a means of evaluating success of a restoration effort. Deviations from the expected trajectory may be considered justification for potential mid-course corrections.

Export of data, results, and "lessons learned" — To be useful, monitoring data, results, and "lessons learned" have to be shared. Information resulting from a well-designed and conducted monitoring program supports the timely and successful management of on-going restoration projects. Project managers can use results in adaptive management to make mid-course corrections in the operation of project features. Additionally, monitoring information regarding the performance of both a project overall and its constituent features is highly useful to individuals designing current and future projects with similar features and goals or in similar habitats. Monitoring data, results, and a discussion of lessons learned should be made available through a publicly available source such as a well-advertised web page. A goal of this process should be the long-term reduction of monitoring costs through implementation of increasingly efficient approaches.

Figure 12. Using a canoe to sample for adult insects in a marsh on the Black River in New York along Lake Ontario. Photo courtesy of Doug Wilcox, United States Geological Survey.

Figure 13. Fyke net sampling along Marshy Creek North, Knapps Narrow, Maryland. Photo courtesy of Dave Meyer, NOAA Restoration Center. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/habrest/r00psc01.htm

The Process of Developing a Monitoring Plan

When developing a scientifically based and statistically valid restoration monitoring plan, a logical process should be followed that considers a sequence of twelve steps:

1. Identify the goals of the project established in the project planning documents and any applicable watershed restoration plan.
2. Identify the type of restoration project and collect information on the monitoring of similar projects.
3. Identify and describe the extent of the habitats within the project area.
4. Define basic structural, functional, and socioeconomic characteristics.
5. Consult experts.
6. Determine hypotheses to be tested in determining progress toward project goals.
7. Collect historical data and indications of trends and causes of decline.
8. Identify reference sites.
9. Identify monitoring time span.
10. Identify monitoring techniques.
11. Design a monitoring review and revision process that complies with the requirements of the restoration program.
12. Develop a cost estimate for implementation of the monitoring plan and compare to available funds.

1. Identify the goals of the project established in the project planning documents and any applicable watershed restoration plan – All restoration projects have identified goals. The monitoring of a restoration project should be designed to determine if the project is functioning as planned and to test progress toward the project goals. These goals are usually identified in the project proposal and design documents and should have been developed through discussions among scientists, socioeconomists, and the affected community. In addition to project goals, regional restoration goals need to be considered to determine the contribution the project in question is making to the restoration of the bay or watershed as a whole. Steps 2 through 12 of this process of developing a monitoring plan should be reflective of the goals of the restoration project.

2. Identify the type of restoration project and collect information on the monitoring of similar projects – Coastal restoration projects tend to fall into a series of broad categories including, but not limited to hydrologic restoration, shoreline stabilization, and vegetative planting. While techniques can be new and innovative, consideration of approaches taken by others conducting restoration monitoring of projects within the same category can be exceptionally helpful in the development and implementation of a successful monitoring plan.

3. Identify and describe the extent of the habitats within the project area – It is critical that the area to be affected by a restoration project be determined and the habitats within that area be identified and mapped. The areal extent of habitat will contribute to the baseline for assessment of habitat gains toward the ERA goal of one million acres by 2010. The acreage counted toward this goal will be those acres over which monitoring can demonstrate improved function[5]. This information can drive the selection of variables to be monitored and provides basic information to be used to determine historical patterns of habitat change, as well as the impacts of the project.

4. Define basic structural and functional characteristics for those habitat types – Each coastal habitat has structural components that define that habitat. The functional components are the processes going on within and between habitats and their structural components. The ultimate goal of any restoration action should be to return functions and not simply build structure. Understanding the structure and function of a habitat allows an understanding of the fundamental ecology of the system and selection of those parameters most relevant to the goals of the project. In selecting characteristics for monitoring, both structural and functional characteristics should be included and should be integrators of several factors. For example, the number and type of birds on a beach are structural parameters. The type may indicate food resources; likewise the absence of normal bird species may be indicative of the absence of their preferred food. The length of time a species spends there may be a function of availability of food, as well as the type of food available. As noted in item 3 above, improved function is a part of the metric that will be used to determine progress toward meeting the overall goal of the Estuary Restoration Act of 2000. Indications of function should be monitored.

Though there is a set of structural and functional characteristics usually measured in a habitat, each restoration monitoring plan generally will be unique because it should provide information to support the assessment of the project goals. The information provided should be used as a starting point and should be augmented based on local conditions and the goals of both the project and the large-scale restoration effort.

[5]*Personal communication, August 13, 2003, Mary Baker, NOAA Office of Response and Restoration.*

The first matrix in Appendix II lists the physical and biological characteristics for habitats that have a high probability of being monitored as a part of coastal restoration project. Within each list, some characteristics should be monitored in any restoration project constructed in that habitat type, regardless of the specific goals. Other characteristics can also be monitored, depending on the goals of the project or watershed level restoration effort. The second and third matrices in Appendix II then assist the restoration practitioner in determining the parameters appropriate for monitoring those characteristics in the appropriate habitat.

5. Consult experts – Individuals or groups developing restoration monitoring plans should never work in isolation. It is imperative that a statistician be consulted early in the process. Additionally, ecologists, hydrologists, botanists, economists, or other scientists with appropriate fields of specialization should review the plan and provide advice on sampling approaches. It would be valuable, as well, to contact resource managers conducting similar monitoring for input as to lessons learned. In *Volume Two: Tools for Monitoring Coastal Habitats*, lists of experts who have agreed to make themselves available for questions will be provided by habitat.

6. Determine hypotheses to be tested in determining progress toward project goals – For each project goal and applicable regional restoration goal, at least one set of testable hypotheses should be created. A set of hypotheses includes a null hypothesis that describes a condition of no change or difference (i.e., salinities in the project area before and after implementation will be equal) and at least one alternate hypothesis that describes a potential change (i.e., salinity within the project area will decrease after the implementation of the project). A statistician should be involved with the establishment of these hypotheses. Further discussion of null and alternate hypotheses can be found in any introductory statistical textbook.

7. Collect historical data and indications of trends and causes of decline – Historical data, if available and of reliable quality, should be obtained for use in determining long-term trends in habitat change. The quality of these data needs to be assessed early in the project design process. Historical information can also provide insight into how the habitat functioned prior to degradation and provide a general baseline of ecological function.

8. Identify reference sites – *Appropriately* selected reference sites allow for the evaluation of progress toward restoration endpoints and the accurate assessment project performance. Two types of reference sites can be used: natural or disturbed. Reference sites reflecting natural conditions serve as indicators of endpoints for the restoration effort. Disturbed reference sites provide information on the rate of recovery, serving as an indication of potential conditions in the project area had the project not been constructed. Using several reference sites forms a basis to judge the progress the restored habitat makes in approaching the structural and functional status of a comparable natural system (Weinstein et al. 1997). The more reference sites used, the more valid the comparison. Progress toward restoration goals can also be evaluated by comparing to reference conditions. The sampling of reference sites should be coordinated with the sampling conducted in the project area.

In addition to reference sites, extensive pre-construction monitoring can be used to provide reference conditions against which the project area can be compared. Analysis of pre- and post-

construction conditions within the project area can be valuable, particularly when paired with the use of reference sites. If no site is available that adequately parallels the current condition of a project area, reference conditions can be used as the sole source of comparison for the project area. Reference conditions, however, are limited in that they do not allow for natural variability in parameters from year to year. Factors beyond the scope of the project, such as a drought or severe storm, can cause significant impacts to the area being restored. Reference sites would reflect this variability when reference conditions probably would not.

Restoration projects often attempt to recreate habitat conditions that were historically present in an area. In situations where records of historic plant and animal species and physical conditions are available, those records may be used as the reference condition to which a restoration project may be compared. Detailed records of the plant and animal species that inhabited a particular coastal habitat, however, are rarely available. In these situations or where restoration of historical conditions is not possible, restoration sites need to be compared to existing sites. Reference sites may be chosen in a variety of manners depending on vegetation type, geomorphology, hydrodynamics, degree of degradation, habitat or hydrologic functions, or landscape-scale characteristics. A review of approaches used in the selection of appropriate monitoring reference sites and conditions is available in the *Volume Two: Tools for Monitoring Coastal Habitats*.

9. Identify the monitoring time span – The restoration monitoring plan should include a detailed schedule of what characteristics are to be monitored when and for how long. All methods used to monitor the restoration project after implementation need to be identified. This helps ensure that baseline and reference site data will be comparable to data collected during monitoring. The monitoring time span for a restoration project is composed of three factors: seasonality, frequency, and duration. Each of these depends on the specific goals of the project and the performance criteria selected for monitoring.

Seasonality

Vegetation communities; fish, wildlife, and migratory bird use; hydrologic patterns; water chemistry; and other structural and functional aspects of coastal habitats often change over various time scales. Tidal patterns follow a lunar cycle, migratory birds may pass through an area only once or twice a year, flooding typically follows seasonal precipitation patterns, herbaceous plants can be present (even dominant) for only a short portion of the growing season, and fish and amphibians may use an area for only a few weeks for spawning or as a nursery area for their young. Each characteristic chosen as part of a monitoring plan will have its own seasonal requirements that need to be addressed and incorporated into the monitoring schedule before data collection in the field. Even then, monitoring schedules or parameters may need to be changed after initial sampling. For example, the determination of migratory bird use of restored or reference areas might not be physically possible with available equipment due to seasonal flooding. A change in the chosen metric, the season of sampling, or the purchase of different equipment may be necessary to complete sampling as planned.

Ideally, both reference and restored areas would be sampled each time sampling is done. This would ensure any natural variation these sites experience from year to year is characterized

and not attributed to the restoration effort. Resources, however, may not provide for such a rigorous sampling schedule. In these cases, sampling of specific parameters in reference areas should take place during the same time of year as sampling in restored areas. For example, since herbaceous plant communities change throughout the year, sampling in restored and reference sites needs to occur during the same season (preferably the same month). This is true also for sampling of invertebrates, fish, migratory birds, water chemistry, algae, and zooplankton.

Figure 14. Freshwater marsh in spring.

Figure 15. Freshwater marsh in late summer.

Figures 14 (spring) and 15 (late summer) are photographs taken from different vantage points of the same marsh (yellow arrow marks landmark trees in the background) in southeastern Michigan. These photos illustrate the importance of accounting for seasonality in restoration monitoring. Monitoring projects that seek to compare restored vegetation communities over time or compare reference areas to restored sites should take measurements as close to the same time each year as possible to ensure comparability of data. Photos courtesy of David Merkey, NOAA Great Lakes Environmental Research Lab.

Frequency

The frequency of monitoring and the type of characteristics measured change over time as the restoration project develops, both structurally and functionally. Three different restoration monitoring phases are identified and described: post-implementation, intermediate, and long-term. The emphasis on which types of characteristics are monitored changes as the system matures.

Post-implementation monitoring occurs over the first (and sometimes second) year after project implementation. The focus is on structural, physical-chemical characteristics, and other habitat parameters directly manipulated as part of the restoration. Immediately after construction, the site should be monitored weekly to check for erosion and sedimentation and to ensure any water control structures or irrigation equipment are functioning properly. Once these components are functioning properly, monitoring can be scaled back to a monthly schedule for the rest of the post-implementation phase (Clewell and Lea 1990). Weekly monitoring is done to gauge early progress of the restoration and identify errors resulting from poor site preparation so any potential problems may be identified and corrected quickly. Examples of post-implementation monitoring are as follows:

- Percent seedling survival
- Plant cover and composition
- Density and composition of organisms living on oyster reefs
- Sediment grain size
- Erosion rates
- Sediment and water column salinity

The hydrology of the system should also initially be monitored closely to ensure it is acting according to plan. As individual structural or functional characteristics begin to meet project goals, monitoring can be done annually or every few years to ensure that the system is still functioning according to plan.

During intermediate years (e.g., 2 - 4 years after implementation), the focus of monitoring often shifts from basic structural components to a combination of both structural and functional characteristics where possible. Functional measures integrate a variety of structural characteristics and provide information on ecological community interactions and habitat contribution. For example, once the restoration effort has good seedling survival and plant cover and composition, these measurements are at first scaled back from monthly to seasonal or annual sampling times and eventually replaced with measures of growth, biomass production, or wildlife use. For some slow growing habitats such as reefs or forests, this shift in monitoring focus and frequency takes longer. Allen et al. (2001) recommends waiting 3 - 5 years after planting to even begin assessing seedling survival and stocking rates in restoration of forested systems.

The long-term phase of monitoring begins once the restoration project has reached, or is on a definite trajectory toward achieving, its structural and functional goals. During long-term monitoring, measurements should be taken annually or every few years, depending on the measurement in question and the goals of the project. Functional or process oriented studies should continue at a statistically supported frequency and on a schedule required to address the hypotheses in question.

Duration

The span over which restoration monitoring should be conducted generally depends on processes to be evaluated and the habitat to be restored. Suggested time frames published in the literature range anywhere between three to fifty years (D'Avanzo 1990; Zedler 1995; Bradshaw 1996; Mitsch and Wilson 1996; Simenstad and Thom 1996; Fonseca et al. 1998; USACE-WES 1999) depending on the objective of the restoration project.

Project monitoring should cover a time period appropriate to statistically evaluate change in the characteristic in question. If a restoration project entails only subtle changes in a degraded habitat, the restoration can achieve its functional goals in as little as three years (Weller 1995). If, however, a more complex restoration is attempted or the entire system requires reestablishment, functional goals may not be achieved for several decades (Mitsch and Wilson 1996). The restored system needs time to develop a range of ecological functions and human values. The monitoring should be long enough to accurately assess this process. Whenever possible, it is recommended that monitoring continue until the system is self-sustaining.

At an absolute minimum, restoration monitoring should be done for at least five years following the completion of project construction (Clewell and Lea 1990). In most habitats, however, the time period over which monitoring should be conducted will be substantially longer (Block et al. 2001; Conner et al. 2000; Kellogg and Bridgham 2002; Mitsch and Wilson 1996; Simenstad and Thom 1996; Streever 1999).

Figure 16. Sediments at Port Sheldon drowned-river-mouth wetland in the Great Lakes area exposed by low lake levels in 1999. Photo courtesy of Doug Wilcox, United States Geological Survey. http://www.glsc.usgs.gov/science/wetlands/waterlevels.htm

10. Identify monitoring techniques - In most cases, there are multiple statistically defensible approaches to restoration monitoring any given habitat. After extensive review of monitoring programs and plans of similar projects, work in similar habitat types, or plans that overlap geographically with the project in question, monitoring planners should outline the project design and rationale, sampling frequency, and characteristics of interest and link them to project goals. The sampling methods and approach should be described in detail for review and should be based on sound statistical sampling design. Additionally, the number of sampling stations, location of those stations, and the number of samples collected are critical decisions that impact the power of the analyses. It is strongly recommended that a statistician be consulted. Whenever possible, the sampling methods used should be non-destructive.

Figure 17. Port Shelton in 2001 after seedbank germination and colonization of exposed substrate by wet meadow vegetation. Photo courtesy of Doug Wilcox, United States Geological Survey. http://www.glsc.usgs.gov/science/wetlands/waterlevels.htm

Experimental studies can be performed onsite in conjunction with restoration and monitoring. Restoration science will continue to be refined through carefully planned and executed experiments and peer-reviewed manuscripts. Controlled, replicated field experiments can illustrate successes and failures in restoration methodologies and techniques. Both successes and failures need to be documented and published to further restoration science. In many instances, these experimental studies could be built into select restoration projects through dedicated funds.

11. Design a monitoring review and revision process that complies with the requirements of the restoration program – Monitoring data should be made available to restoration practitioners and decision makers, both those working on the project in question and those who could apply the lessons learned, to maximize the usefulness of the data. Monitoring reports need to include careful assessment, review, analysis, and synthesis of results in addition to presentation of results and simple statistics. The lack of synthesis is a major shortcoming of some restoration monitoring programs; information, data and concepts are not brought together in a way that is easily understood by a wide audience (M. Posey, University of North Carolina - Wilmington, pers. comm.).

There should be a reporting system and schedule that makes data and results interpretation available in a timely manner and in a useful format. A well-designed and easily accessible reporting system facilitates adaptive management at both the project and watershed or bay system level. A Quality Assurance/Quality Control (QA/QC) plan should be developed that outlines the means of data collection, formatting, storage, and public accessibility. Examples of QA/QC documents can be found under each habitat of *Volume Two: Tools for Monitoring Coastal Habitats*.

Managers should be held accountable for complying with this plan. Restoration monitoring data are most valuable when consistent with or easily convertible to standard data formats already in general use. This allows the results of the monitoring effort to be analyzed and applied by people designing or evaluating both this and other restoration projects. Additionally, it allows project and monitoring managers to assess the monitoring plan itself. If, despite a thorough planning process, a monitoring effort is not adequately assessing progress toward restoration goals, the monitoring plan should be modified.

For projects funded under the ERA, information on habitat extent must be presented in acres to allow for assessment of progress toward the Act's goal of restoring one million acres of coastal habitat. For other restoration monitoring variables, data should be collected in the format that is the established standard for that variable and technique. In *Volume Two: Tools for Monitoring Coastal Habitats,* monitoring techniques manuals are included for each habitat considered. Additionally, a database is presented that reviews coastal restoration monitoring programs. Links are provided to these programs that provide access to manuals, QA/QC documents, and standards established for these programs.

12. Develop a cost estimate for implementation of the restoration monitoring plan and compare to available funds – A restoration monitoring plan should provide for sufficient personnel, funding, and authority to provide all easements, rights-of-way, maintenance, and monitoring. The cost of monitoring varies, depending on techniques used, frequency of sampling, and the length of time over which monitoring is conducted. In some cases, the amount of money available from a project budget for monitoring is determined by the authorizing legislation or by agreement among participating parties. In all cases, determining the percentage of a restoration budget to be allocated to monitoring is a balancing act where costs need to be built in up front. One should dedicate enough resources to monitoring so the assessment of project impacts and progress toward goals is statistically and scientifically valid. The monitoring, though, should not eclipse the restoration work. Sample costs associated with coastal restoration monitoring are provided in *Volume Two: Tools for Monitoring Coastal Habitats*.

Writing a Restoration Monitoring Plan

A restoration monitoring plan should contain certain basic information that allows managers, scientists, and statisticians participating in the monitoring over the long term run of the project to understand what is to be done, when it is to be done, and why it was included in the plan. These critical plan elements are as follows:

Background Material

- Description of the project area, including habitat types and acreage, and estuary/ watershed
- Discussion of the habitat trends and causes of loss or decline in the area
- Review of the project, including components and the time table

Project Goals and Objectives

- Goals and objectives defined for the project
- Goals and objectives of the regional restoration plan that are relevant to this project

Monitoring Components

- Listing of habitat characteristics or functions to be monitored in the assessment of progress toward project and regional restoration goals
- Statement of the null and alternative hypotheses to be tested as a means of assessing progress toward project and regional restoration goals
- Discussion of the reference sites to be used, including location and the methods used in and justification for selection of the sites
- Detailing of pre-construction sampling and data mining to be used in establishing historical and baseline conditions, including techniques, frequency, and sampling QA/QC
- Detailed plan for sampling during and after construction, including techniques, frequency, sampling QA/QC, and provisions for adaptive management
- Detailed discussion of statistical analysis to be employed in hypothesis testing
- Detailed plan for data handling, storage, and accessibility (data QA/QC procedures)
- Report preparation and distribution plan
- Provision for review of the effectiveness and efficiency of the monitoring plan after implementation

Projected Monitoring Budget

- Estimates of the costs associated with the implementation of the monitoring provided by category of cost and year

Participants and Contact Information

- Contact information for the restoration project manager and monitoring plan manager
- List of the individuals involved in the development and review of the plan

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OVERVIEW OF VOLUME TWO: TOOLS FOR MONITORING COASTAL HABITATS

Volume One of *Science-Based Restoration Monitoring of Coastal Habitats* provides guidance on designing and implementing scientifically defensible monitoring plans. Volume Two contains the tools to aid the development and implementation of a plan. Together, these volumes focus practitioners on key habitat characteristics to be monitored and provide assistance in the selection among the many available monitoring techniques. This will result in the collection and dissemination of timely information that can be used in project and estuary or watershed level adaptive management, as well as contribute to the improvement of the design, construction, and monitoring of future projects.

Volume Two: Tools for Monitoring Coastal Habitats includes seven parts:

- Coastal Habitats: Ecology, Restoration, and Monitoring
- Selection of Reference Sites or Conditions
- Review of Restoration Monitoring Programs in the United States
- Review of Acts Relevant to Restoration Monitoring
- Sample List of Costs Involved in Restoration Monitoring
- Review of Socioeconomic Factors Associated with Restoration Monitoring
- Glossary

Coastal Habitats: Ecology, Restoration, and Monitoring provides a review of the ecology and restoration monitoring approaches applied within the marine and Great Lake coastal habitats listed earlier in this document. An introduction and description of each coastal habitat type is listed. Habitat structure, including dominant species and prevailing factors, and habitat functions and ecological values are explained for each habitat type and supported by case studies. Common anthropogenic impacts on each coastal habitat are described. Examples of significant restoration monitoring projects on each coastal habitat are listed and briefly described. Finally, a list of experts who have provided input to this document and are willing to answer detailed questions will be provided for each habitat.

Coastal Habitats: Ecology, Restoration, and Monitoring also presents two annotated bibliographies for each habitat that will assist practitioners with planning, designing, restoration, and monitoring. The first annotated bibliography for each habitat includes summaries and case studies of recent monitoring projects. Each of the entries includes the source and a short abstract of various studies that have been conducted for restoring and monitoring the habitat. The second annotated bibliography for each habitat includes commonly used protocols and techniques manuals used in coastal habitat monitoring for those in need of ideas on how to monitor the habitats in their restoration project. The techniques manuals discussed here are not recommended as the standard for all monitoring, but are suggested as examples that should be modified with each monitoring project. These annotated bibliographies include both gray and peer-reviewed literature, but are not all-encompassing. The entries within the bibliography are arranged in alphabetical order either by the author's last name or by source. The techniques manuals discussed here are not recommended as the standard for all monitoring, but are suggested as examples that should be modified with each monitoring project. Finally, a list of experts who have provided input to this document and are willing to answer detailed questions will be provided for each habitat.

Selection of Reference Sites or Conditions reviews the methods available for choosing areas or conditions to which a restoration site may be compared, both for the purposes of setting goals during project planning and for monitoring the development of the restored site over time. Without the use of reference sites or conditions, a restoration practitioner would be unable to appropriately determine what plant or animal species to introduce to an area, which abiotic characteristics to create, and if changes in a restoration site over time were caused by natural variation or were actually the result of restoration efforts.

Review of Restoration Monitoring Programs in the United States is a review and inventory of current and significant regional restoration monitoring programs in the United States and its protectorates. Information on each monitoring program will be compiled into an easily searchable database available on the Internet. This review of restoration monitoring programs will allow restoration practitioners to locate regional monitoring programs that may serve as models for the establishment or improvement of their own efforts. Monitoring programs selected for inclusion in the database are current or have easily accessible, extensive data. This database is not meant to be comprehensive, but will serve as a list of significant examples of restoration monitoring programs in the United States.

Information presented on each monitoring program is intended to give the general scope of the program. Contact information and references are provided to allow the reader to gather more detailed information as needed. Specifically, the database provides the name, website address, supporting agency, location and region, secondary website address, status, start and end date, habitat types, metrics, contact name and information, goals and objectives, and descriptive notes for each monitoring program.

Review of Acts Relevant to Restoration Monitoring is a summary of the major United States Acts that support restoration monitoring. Responsibility for restoration and monitoring of coastal habitat is a shared responsibility among the states, Tribal Nations, and other Federal departments of the United States The Acts described in this section include the Estuaries and Clean Waters Act of 2000, Anadromous Fish Conservation Act, the Clean Water Act, the Endangered Species Act, Marine Protection Research and Sanctuaries Act, the Fish and Wildlife Coordination Act, the Magnuson-Stevens Fishery Conservation and Management Act, and the National Environmental Policy Act.

Sample List of Costs Involved in Restoration Monitoring is designed as a general aid in the development of planning preliminary cost estimates of restoration monitoring activities. Estimates on costs of personnel, labor, and equipment are provided on a daily or hourly rate. These examples of planning cost estimates will vary by region and demand and can be updated by a cost inflation factor.

Review of Socioeconomic Factors Associated with Restoration Monitoring is a review of methods for gauging the socioeconomic impacts of restoration projects. It will identify the socioeconomic goals commonly associated with coastal restoration projects and discuss the relationship between the ecological objectives and the socioeconomic benefits. Additionally, the document will examine metrics used to monitor progress toward socioeconomic goals and will present an annotated bibliography of references on socioeconomic factors in restoration projects.

Glossary contains definitions for terms commonly used in coastal habitat restoration and monitoring.

Future Documents

After publication of Volumes One and Two of *Science-Based Restoration Monitoring of Coastal Habitats*, the authors will develop a series of habitat and issue-specific documents for selected habitats. Each document will include a summary of common protocols used in restoration monitoring, a list of experienced scientists willing to answer questions, examples of monitoring for past and current projects, a summary of current research related to restoration and monitoring, a discussion of common problems in restoration monitoring, and the prominent socioeconomic issues surrounding monitoring. These habitat-specific documents will supplement the information presented in this manual and will be written for both scientists and non-scientists.

Figure 18. Grab sampler being used to determine soft bottom characteristics. Photo courtesy of Robert A. Pawlowski, NOAA Corps. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/fish/fish1017.htm

APPENDIX I: COASTAL HABITATS

In most cases, coastal habitats are multi-dimensional, complex ecosystems defined by a variety of structural and functional characteristics. One of the critical steps in developing a monitoring plan is to determine the characteristics that accurately reflect the goals and objectives of the restoration effort and are therefore appropriate for monitoring. The habitat descriptions below, coupled with the 3 matrices involving habitat characteristics and measurement parameters (Appendix II), are designed to assist restoration practitioners in determining which habitat characteristics are considered important for inclusion in monitoring plans by expert opinion, depending on the goals of the project. These characteristics are ecological parameters to evaluate the progress toward project goals.

For organizational purposes, the habitat descriptions roughly follow a progression from open water inland. Wherever appropriate, definitions apply to both freshwater and marine examples. The habitats are as follows:

- Water column
- Rock bottom
- Coral reefs
- Oyster reefs
- Soft bottom
- Kelp and other macroalgae
- Rocky shoreline
- Soft shoreline
- Submerged aquatic vegetation [SAV; seagrasses (marine/brackish) and freshwater]
- Marsh (marine/brackish and freshwater)
- Mangrove swamps
- Deepwater swamps
- Riverine forests

WATER COLUMN

Physical Description – The water column is a conceptual volume of water extending from the water surface down to, but not including, the substrate. It is a dynamic environment subject to waves, currents, tides, and riverine influences. It is found in marine, estuarine, river, and lacustrine systems.

In marine systems, water regimes are determined primarily by the ebb and flow of ocean tides, movement of nearshore currents, freshwater inputs from tributaries, and ice cover (Day et al. 1989). The quality of the water column affects all associated habitats. Estuarine water regimes are dominated by their widely varying salinities, from seawater (approximately 35 ppt) to fresh water (approximately 0.5 ppt) (Day et al. 1989; USEPA 2001). Water level may be controlled by lunar tides and wind events; the relative importance of each varies with location. In Great Lake systems, water regimes are dominated by the annual and seasonal water level fluctuations of the lakes and short-term (daily) fluctuations caused by seiches (Bedford 1992; Herdendorf 1990). Seiches are

Figure 19. Water body running through marsh vegetation on the Mid-Patuxent River, Maryland. Photo courtesy of Mary Hollinger, NOAA National Oceanographic Data Center. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/coastline/line0619.htm

wind driven tides that may last from a few minutes to several hours and range in size from a few centimeters to several meters depending on the severity and duration of storms or wind creating them.

Biological Characteristics – In all water columns (from marine to freshwater) food webs are supported almost entirely by phytoplankton (photosynthetic organisms that account for about 95% of the ocean's primary productivity) (Day et al. 1989). In some systems and at certain times of year, it is likely that benthic algae and detritus suspended by wave action and other forms of disturbance may also be important (Day et al. 1989). The presence of pelagic fauna and flora within the water column results from both physical factors as they relate to topography and to mixing of communities from adjacent areas (Gibson et al. 2000). Salinity determines which fauna and flora ultimately reside in the estuary water column (Bulger et al. 1993).

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ROCK BOTTOM

Physical Description – Rock bottom habitats may consist of bedrock, rocks, boulders, gravel, or pebbles. These rocky materials are transported and sorted by geologic activity, ice, currents, or continuous wave action. Rock bottom habitats occur in freshwater as well as marine environments. However, the freshwater rocky bottom habitats are not as well studied as their salt water counterparts described below.

Biological Characteristics – Rock bottom habitats support a variety of marine organisms ranging from seaweed and algae to fish and shorebirds. Many organisms rely on rock bottom substrates for attachment in order to survive, grow, and reproduce. Rock bottoms support filter-feeding organisms such as barnacles and oysters that help maintain water quality and stabilize bottom sediments, reducing turbidity and lowering shoreline erosion rates. Species such as fish, crustaceans, and some worms live in crevices of the rock bottom habitat. Shorebirds rely on rock bottom habitats for feeding and resting.

Plant species that commonly colonize rock bottoms include macroalgae (*Furcellaria lumbricalis)* (Kotta and Orav 2001), kelp (*Macrocystis)*, seaweed, brown algae (Phaeophyta), red algae (Rhodophyta), green algae (Chlorophyta), and coralline algae found on coral reefs. Predation, grazing, and physical factors help control zonation of attached species in these habitats (Barnes and Hughes 1988).

Some animal species occupying rock bottoms include mussels (e.g., zebra mussels, *Dreissena polymorpha*), queen conch (*Strombus gigas* around Florida Keys) (McCarthy et al. 2001), sea urchins (e.g., *Strongylocentrotus purpuratus*), chitons (e.g., spiculed chiton, *Acanthoplera gaimardi*), and limpets (*Fisurella* spp.). Fish too, use rock bottom habitats for feeding and protection from predators. Fishes such as Goliath grouper (*Epinephelus itajara*), common snook (*Centropomus undecimalis*), spotted seatrout (*Cynoscion nebulosus*), cobia (*Rachycentron canadum*), and red snapper (*Lutjanus erythropterus*) are commonly found in rock bottom habitats. Shrimp (Family Hippolytidae), the Chesapeake Bay whelk (*Rapana venosa*) (Harding and Mann 2000), oysters (*Crassostrea gigas*), brittle stars (*Ophiopteris papillosa*), and sessile organisms such as sponges, sea anemones, soft corals, bryozoans, barnacles, and tube-dwelling polychaetes are also common residents of these systems. Physical characteristics in areas such pebble or cobble beaches can have a significant impact on the reproductive success of both transient and resident organisms.

Figure 20. A rock bottom habitat in the Great Lakes covered with zebra mussels (*Dreissena polymorpha*). Photo courtesy of John Janssen, Great Lakes Water Institute, University of Wisconsin, Fl.

Figure 21. Marine rock bottom (basalt flows) with Duckbill eel (*Nessorhamphus ingolfianus*) in a sand channel in Hawaii. Photo courtesy of J. Moore, NOAA Oceanic and Atmospheric Research/National Undersea Research Program (NURP). Publication of the NOAA Central Library. http://www.photolib.noaa.gov/nurp/nur05024.htm

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CORAL REEFS

Physical Description – Coral reefs are rough three-dimensional structures of many small individual, interconnected corals. The reefs generally sit on continental shelves and submerged bases of volcanoes in depths ranging from emergent on low tides to around 150ft (46.72 m). They exist in the cool, shallow, clear waters of tropical and subtropical seas. Most corals cannot survive temperatures below 60^o – 65^oF (16^o – 18^o C) (Turgeon et al. 2002).

Biological Characteristics – Coral reefs are highly diverse ecosystems. They are composed of marine polyps that secrete a hard calcium carbonate skeleton, which serves as a base or substrate for the colony. The living colony continuously deposits calcium carbonate over time, adding to the size of the structure. They are centers of high biodiversity and productivity, providing essential feeding, shelter, breeding, and nursery habitat for a variety of reef fishes, algae, mollusks, and crustaceans.

There are three general types of reefs: fringing reefs around islands, barrier reefs along continents, and atolls. Each is distinctive in its structure and development.

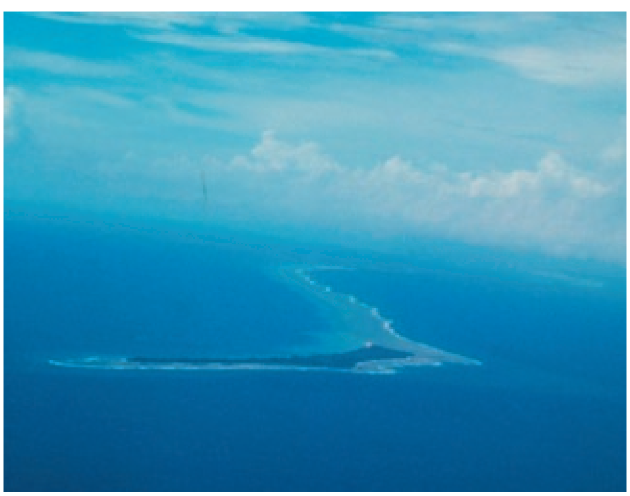

Figure 22. Aerial view of atolls located in Eniwetok. Photo courtesy of James P. McVey, NOAA Sea Grant Program. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/mvey/mvey0237.htm

Fringing Reefs Around Islands – These reefs grow in shallow waters and closely border the coast or are separated from it by a narrow stretch of water. They are comprised of numerous zones characterized by depth, reef structure, and dominant plant and animal communities.

Barrier Reefs Along Continents – These reefs are separated from land by a lagoon. They are large, grow parallel to the coast, and form a continuous barrier between the shoreline and the open ocean. These reefs have zones similar to those found in fringing reefs as well as patch reefs (small reefs), back reefs (the shoreward side of the reef), and bank reefs (reefs that

Figure 23. Koror Harbor east entrance showing barrier reef to outside and patch reefs in lagoon located in Malakal, Koror. Photo courtesy of James P. McVey, NOAA Sea Grant Program. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/mvey/mvey0131.htm

occur on deep bottom irregularities).

Atolls – These develop at or near the surface of the sea when islands that are surrounded by reefs subside. They can be horseshoe-shaped or circular with a central lagoon. There are two types of atolls: those that rise from deep sea and those found on the continental shelf (Goreau et al. 1979).

Many types of fish (e.g., grouper and snapper), crabs (e.g., blue crabs, *Callinectes sapidus*), shrimp (*Parapenaeopsis* or *Solenocera* sp.), sea urchins (*Paramoeba invadens)*, starfish (such as *Echinaster)*, sponges (*Vasum* and *Xestospongia*), and lobster (such as red lobster, *Enoplometapus sp*.) are found on or around coral reefs. The corals also have a symbiotic (mutually beneficial) relationship with algae called zooxanthellae. The algae live inside the coral polyps, photosynthesizing and producing food that is shared with the coral. In exchange, the coral provides the algae with protection and access to light, necessary for photosynthesis (Rowan and Powers 1991). Other vegetative species that live on coral reefs include crustose coralline algae (red algae), calcareous algae, coralline green alga, and green alga.

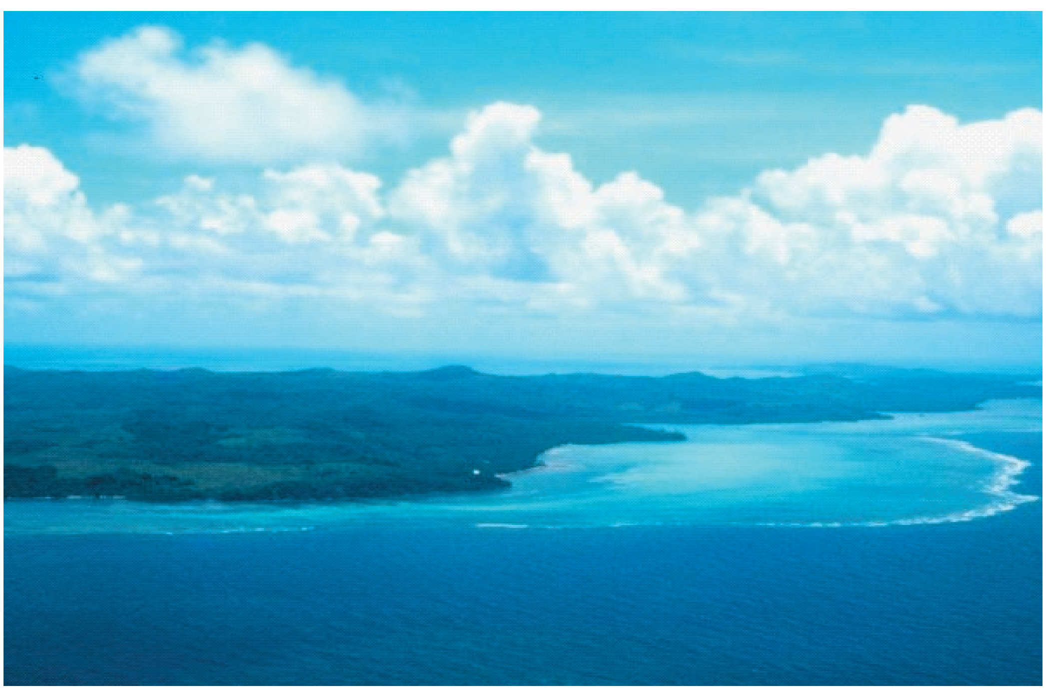

Figure 24. Aerial view of fringing reef adjacent to high volcanic island, located in Palau, Western Caroline Islands. Photo courtesy of James P. McVey, NOAA Sea Grant Program. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/mvey/mvey0038.htm

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OYSTER REEFS

Physical Description - Oyster reefs are dominant features in estuarine systems along the Atlantic and Gulf of Mexico coasts. Oyster reefs form best where bottom currents sweep sediments away, otherwise the oysters can be inundated with their own feces and pseudofeces (material expelled by the oyster without having gone through the animal's digestive system) or other particulate matter to the point where filter feeding is inhibited. These communities occur across many acres of bay bottom and in intertidal and subtidal areas.

Natural oyster reefs may be divided into upward thrusting reefs, which normally occur in deeper estuarine waters, and fringing oyster reefs found in shallow embayments, lagoons, creeks, and shallow tributaries of estuaries. The natural geomorphic, hydrologic, and biologic features present during their development determine reef shape, location, and size.

Biological Characteristics – An oyster reef community is primarily dependent on the import of food resources from other habitats, principally the open-bay water and peripheral emergent marshes (Shipley and Kiesling 1994). Oyster reefs are capable of filtering massive amounts of water, and feeding on plankton and other suspended organic matter. These activities greatly increase water clarity and quality.

Plant species that occupy this habitat, particularly in shallow shoreline areas, include crustal algae. This type of algae attaches to shell substrates and supports a small grazing food chain (GBNEP 1994).

On the Atlantic and Gulf Coasts *Crassostrea virginica* is the common species of oyster. On the Pacific coast, *Crassostrea gigas* is the common species. Fiddler crabs (*Uca* sp.), blue crab (*Callinectes sapidus*), rock crab (*Cancer productus*), grass shrimp (*Palaemonetes sp.)*, mussels (*Mytilus edulis*), rockfish (*Sebastes* sp.), oyster toadfish (*Opsanus tau*), sea ducks (scaups and scooters), and California bat ray (*Myliobatis californica*) are also commonly found using oyster reef habitats (Couch and Hassler 1989). This mosaic of fish and invertebrate species implies close linkages with adjacent habitats as they move in and out of reefs with the changing tides.

Figure 25. Intertidal oyster reefs being built on Fisherman's Island, Virginia. Photo courtesy of Mark Luckenbach, Professor of Marine Science, Director of Eastern Shore laboratory. Virginia Institute of Marine Science, Wachapreague, VA.

Figure 26. New growth seen in Palmetto Island County Park, Mount Pleasant, 2001. South Carolina Oyster Restoration and Enhancement Program. Photo courtesy of South Carolina Department of Natural Resources. http://www.csc.noaa.gov/scoysters/html/photos/sites/palmetto/palm4746.htm

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SOFT BOTTOM

Physical Description – Soft bottom habitats are composed of loose, unconsolidated substrate characterized by fine to coarse-grained sediment. The water depth is relatively shallow and located adjacent to beaches (or other sediment sources). These areas are generally not exposed during low tide. Marine soft bottom habitats include worm mounds and sand dollar beds and are not vegetated. Within the Great Lakes, soft bottom habitats tend to develop in low energy zones such as harbors, embayments, or drowned river mouths.

In most soft bottom areas, wave action produces a relatively coarse, poorly consolidated, well-sorted (low grain size variation), and easily moved sediment deposit. Large waves lift these surface sediments into a suspension that is tossed shoreward and then seaward by the passing waves (Bascom 1981; Clifton et al. 1971). Extreme storm waves can remove as much as a meter of surface sediments at water depths greater than 10 m. The physical stability of the beach deposit increases with increasing water depth as wave-generated bottom currents decrease. As a result, bottom sediments grade from coarse to fine sand with increasing water depth and decreasing wave disturbance (Hodgson and Nybakken 1973; Oliver 1980).

Biological Characteristics – Movement of bottom sediments by waves and currents is a dominant physical process influencing the structure of benthic communities in these areas (Oliver 1980; Simenstad et al. 1991).

The benthic community of these habitats is composed of a wide range of bacteria, plants, and animals from all levels of the food web. Benthic animals are divided into three distinct groups: infauna (animals that live in the sediment), epifauna (animals living on the surface of the sediment or other substrate such as debris), and demersal (bottom-feeding or bottom-dwelling fish and other free moving organisms). Benthic organisms link primary producers, such as phytoplankton, with the higher trophic levels, such as finfish, by consuming phytoplankton and then being consumed by larger organisms. They also play a major role in breaking down organic material. Benthic invertebrates are among the most important components of coastal ecosystems.

In marine soft bottom habitat, the dominant benthic organisms include worms (polychaetes), amphipods, clams, crabs, and flatfish (Simenstad et al. 1991). The invertebrate community includes mud crabs (e.g., *Panopeus* spp.), amphipods (e.g., *Corophium lacustre*, *Jassa falcate*, *Gammarus* spp.), sea squirts (e.g., *Molgula manhattensis*), red ribbon worms (*Micrura leidyi*), whip mudworms (*Polydora ligni*), glassy tubeworms (*Spiochaetopterus oculatus*), common clam worms (*Nereis succinea*), Atlantic oyster drills (*Urosalpinx cinerea*), hard clams (*Mercenaria mercenaria*), soft shell clams (*Mya arenaria*), and blue crabs (*Callinectes sapidus*). Vertebrate organisms include flounders (e.g., southern flounder, *Paralichthys lethostigma*), puffers (e.g., *Sphoeroides parvus*), sea robins (*Peristedion* spp., *Prionotus* spp.), cownose rays (*Rhinoptera bonasus*), spot (*Leiostomus xanthurus*), croaker (*Micropogonias undulatus*), striped bass (*Morone saxatilis*), white perch (*Morone americana*), sablefish (*Anoplopoma fimbria*), shortspine thornyhead (*Sebastolobus alascanus*), longspine thornyhead (*S. altivelis*), and Dover sole (*Microstomus pacificus*).

Within the Great Lakes, the fauna are characterized by low abundance, high diversity, and great variability in both time and space. This variability is due to the physical instability of this zone. Downwelling and oscillating thermoclines cause wide fluctuations in bottom temperatures, and waves and bottom currents cause resuspension of bottom substrates (Cook and Johnson 1974). Dominant freshwater benthic organisms include oligochaetes (*Stylodrilus heringianus*, *Tubifex spp*., *Limnodrilus spp*.), amphipods (*Diporeia, Gammarus spp*.), mayfly (*Hexagenia*), pea mussel (*Pisidium* spp), and chironomid larvae (Barton and Hynes 1978).

Less common is a habitat that develops in low energy zones such as harbors, embayments, or drowned river mouths. These sediments consist of three primary components: particulate mineral matter, organic matter in various stages of decomposition, and inorganic component of

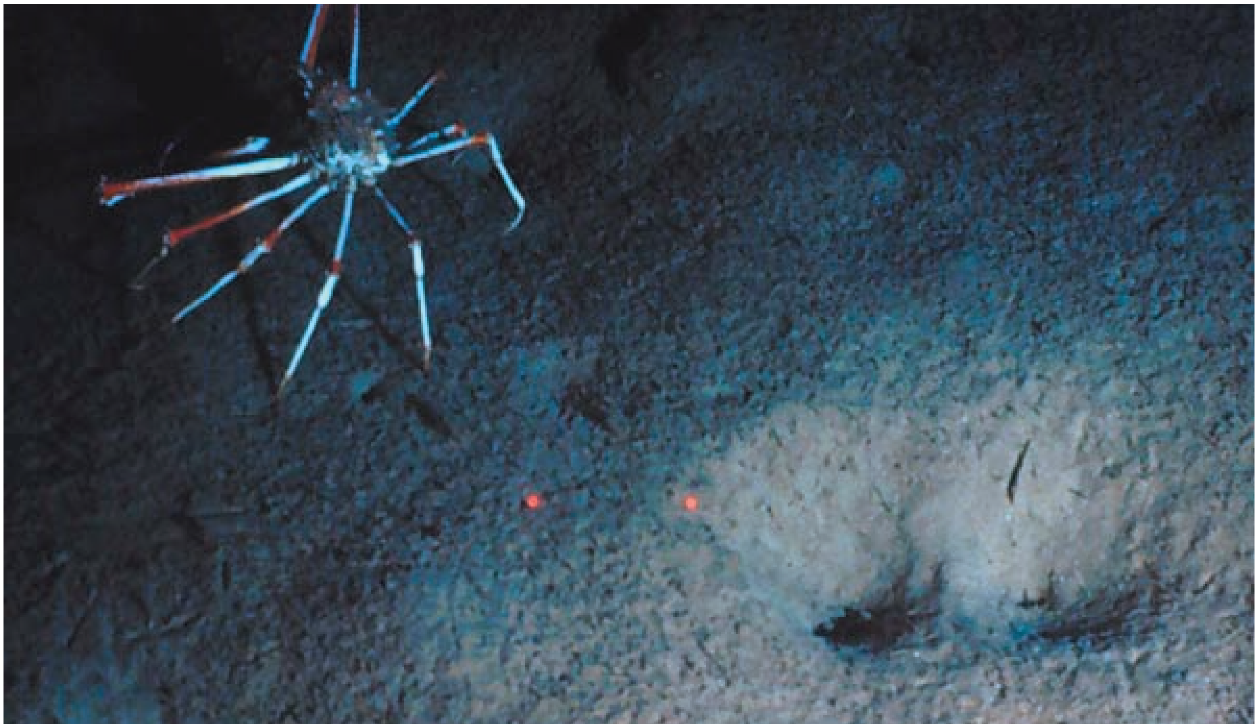

Figure 27. The inflated spiny crab (*Rochinia crassa*) in its preferred habitat, the soft-bottom ooze. Photo courtesy of Betty Wenner, South Carolina Department of Natural Resources. http://oceanexplorer.noaa.gov/explorations/03bump/logs/aug02/media/figure3.html

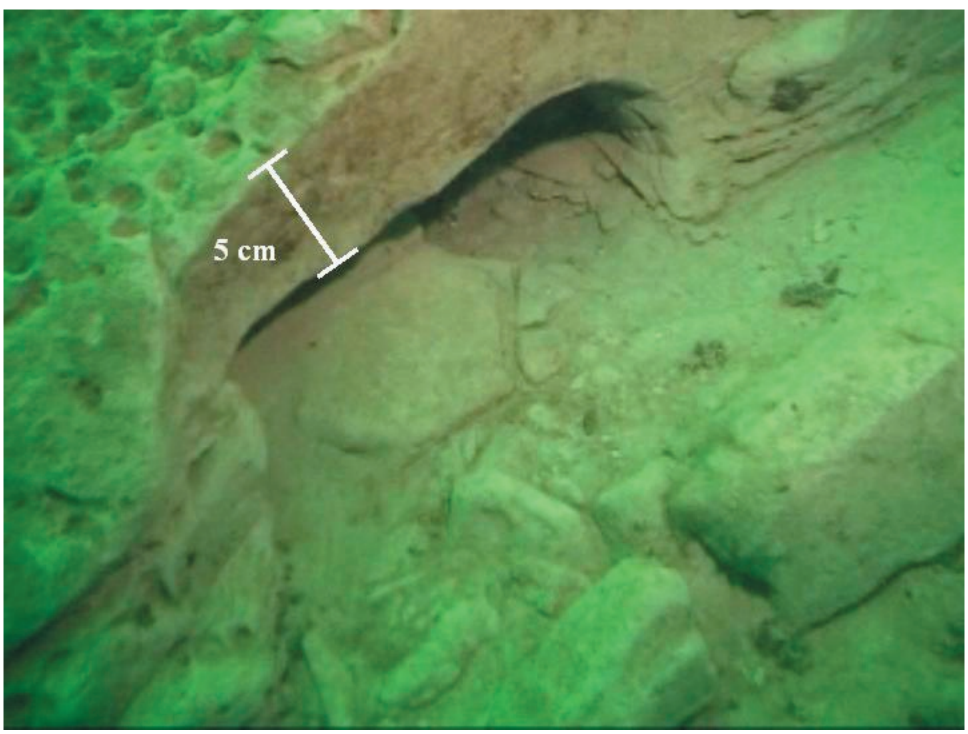

Figure 28. Soft bottom habitats are not just empty expanses of mudflat. Small holes and irregularities such as this one offer haven to animals such as crayfish. Photo courtesy of Marc A. Blouin, United States Geological Survey.

biogenic origin, e.g., diatom shells. Particle size and organic matter of sediments is important to the distribution and growth of benthic invertebrates. Sediments with large amounts of organic matter are found in areas dominated by littoral production (Wetzel 1983). Organisms found in these areas include a variety of aquatic insects and benthic organisms, as well as fish such as adult northern pike (*Esox lucius*), largemouth bass (*Micropterus salmoides*), brown bullhead (*Ameiurus nebulosus*), longnose gar (*Lepisosteus osseus*), common shiner (*Notropis cornutus*), bluegill (*Lepomis macrochirus*), white sucker (*Catostomus commersoni*), creek chub (*Semolitus atromaculatus*), and bluntnose minnow (*Pimephales notatus*).

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KELP AND OTHER MACROALGAE

Physical Description – Kelp and other macroalgae are relatively shallow (less than 50 m deep) subtidal algal communities dominated by very large, brown algae. Kelp and other macroalgae grow on hard substrates forming extensive three-dimensional structures that support numerous floral and faunal assemblages. These forests are commonly found along the west coast.

Kelp forests form canopies that reach 20 – 30 m in water. Kelp beds form at low tide or when the kelp is growing in shallow water (1 - 2 m) (Foster and Schiel 1985). Kelp are restricted to cold water climates because warmer waters tend to lack the rich supply of nutrients that kelp need to flourish. The extent of kelp forests and beds depends on the availability of a hard substrate for attachment and on the availability of light for young plants to grow (a function of water clarity). In addition, kelp is limited by high water temperature, associated low nutrient concentrations, and by grazing.

Biological Characteristics – Kelp beds and forests are highly productive and provide a structurally complex habitat to numerous other seaweeds, invertebrates, and vertebrates found in the kelp

community (reviews in Foster and Schiel 1985, Van Blaricom and Estes 1988, Witman and Dayton 2001). In fact, kelps are among the most productive marine communities in temperate waters. This is due to the interaction of a complex habitat structure; high biomass production; intensive invertebrate, finfish, and marine mammal utilization; and large nutrient import and export.

Kelps are large brown algae (Class Phaeophyceae). They include the largest seaweed in the world, the giant kelp (*Macrocystis* spp.), as well as numerous other genera such as *Laminaria*, *Alaria*, and *Nereocystis* that range in size from a few to tens of meters long. Other macroalgae, such as wracks (*Fucus* spp.), are smaller on average than the kelps and can be diverse in form, with serrations, branches, or bladders occurring on their fronds.

Habitats dominated by kelps such as *Macrocystis* have floating fronds that form a canopy on the surface of the water. These are known as ‘kelp forests’ because of their forest-like structure, while habitats with only a bottom kelp canopy produced by non-float bearing genera such as *Laminaria* are referred to as ‘kelp beds.’ *Fucus* occurs in high energy intertidal areas, strongly anchored by holdfasts to hard surfaces. Kelp generally requires rocky substrate for attachment (Foster and Schiel 1985; Van Blaricom and Estes 1988; Witman and Dayton 2001). Fronds develop from these holdfasts and may grow to the surface if floats are produced.

Holdfasts and dense mats of understory algae and sessile invertebrates (sponges, bryozoans, and tunicates) on the substrate provide sub-habitats and feeding areas for a variety of mobile invertebrates and fishes. In Giant Kelp forests, fishes include garibaldi (*Hypsypops rubicundus*), sheephead (*Semicossyphus pulcher*), and lingcod (*Ophiodon elongatus*). Mobile invertebrates are usually numerous and include crustaceans, echinoderms, and mollusks. Benthic herbivores such as sea urchins (*Strongylocentrotus* spp.) are common, particularly in areas without sea otters (*Enhydra lutris*), and can eliminate almost all macroalgae except corallines.

The mid-water structure and surface canopies produced by float-bearing kelps such as *Macrocystis* spp. provide additional habitat for invertebrates and fishes. Bryozoans, hydroids, isopods, serpulid worms, and turban snails can be found in kelp beds and forests. Fishes such as the senorita (*Oxyjulis californica*), blue rockfish (*Sebastes mystinus*), and kelp bass (*Paralabrax clathratus*) are also associated with kelp communities. Kelp beds and forests are common foraging areas for birds, such as cormorants, and mammals, including harbor seals and sea otters. The latter forage for benthic invertebrates such as sea urchins, abalone (*Haliotis* spp.), and small crustaceans and mollusks when larger prey is depleted. Sea otters also wrap themselves in the surface canopy while resting, presumably to prevent drifting away.

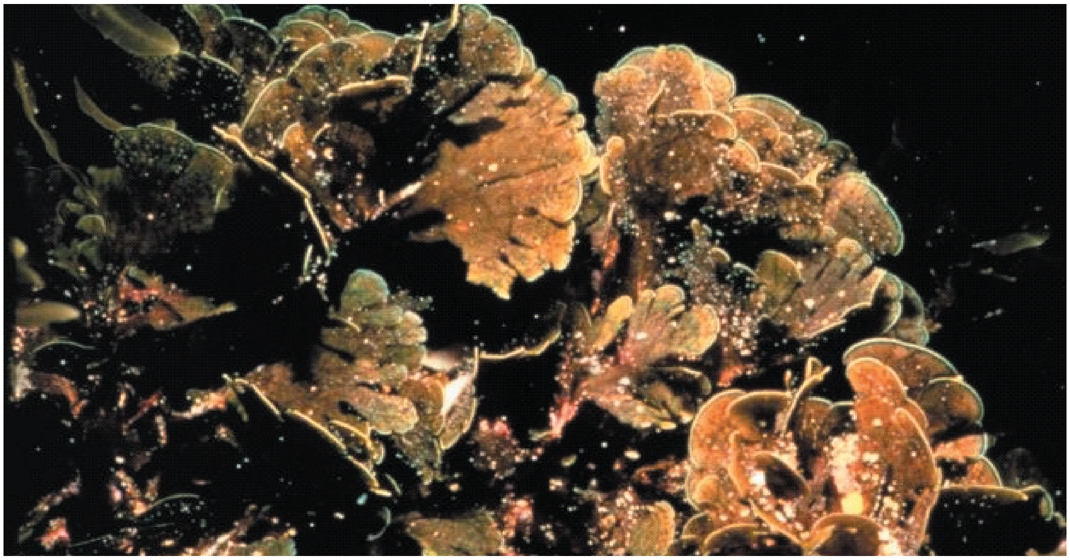

Figure 29. Brown algae on a temperate Carolina reef. Photo courtesy of A. Shepherd, NOAA Oceanic and Atmospheric Research/National Undersea Research Program (NURP); University of North Carolina at Wilmington. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/nurp/nur03508.htm

Figure 30. A giant kelp forest located in Channel Islands National Marine Sanctuary. Photo courtesy of Sanctuary Collection. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/sanctuary/sanc0001.htm

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ROCKY SHORELINE

Physical Description – Rocky shorelines are extensive littoral habitats on wave-exposed coasts. Rocky shores are characterized by sharp environmental gradients from low rocky intertidal to upper intertidal.

Rocky shores are composed of bedrock and cobble in tidal and non-tidal areas. Tidal rocky shorelines are commonly exposed to the pounding of waves and the water level can vary substantially. For non-tidal rocky shorelines, the water level varies annually and seasonally. Variation within a single day is less common than on tidal shores. There are three zones on the rocky shores. The supralittoral zone is known as the splash zone; the eulittoral zone is the intertidal range between the low and high water level; and the sublittoral zone extends below the low water mark (Little and Kitching 1996). Rocky shores provide several functions such as biomass export, wave energy attenuation, spawning and nursery habitat for fish, invertebrate habitat, and bird and mammal feeding grounds. In the Great Lakes, cobble and bedrock rocky shorelines are recognized. In many marine areas rocky shorelines are habitat for some kelp and many gastropods.

Biological Characteristics – Predation, grazing, and physical factors are important in controlling the zonation of sessile species in these habitats (Menge 1983). The species success in non-tidal and tidal areas varies based on local conditions and the physiological tolerance of the organism (Connell 1972). For example, macroalgae thrive in areas not exposed to high light intensity, high temperatures, and desiccation (upper shorelines). Therefore, macroalgae tend to live in intertidal to tidal zones where the water depth is greater (Barnes and Hughes 1988). Seaweed (e.g., *Fucus*) also is found along rocky shorelines, mainly in the eulittoral to the infralittoral zone, and provides a source of nutrition to mobile organisms that live throughout the tidal zone and are tolerant of exposure to light and air (Barnes and Hughes 1988).

Common plants found on rocky shores are red algae, green algae, and brown algae. Examples of these species include *Microcladia coulteri* and Turkish towel (*Gigartina exasperata*) which are red algae; feather boa kelp (*Egregia menziesii*) which is brown algae; and sea moss (*Bostrichia montagnei*) which is green algae (Little and Kitching 1996). Some mobile animals occupying rocky shores include crabs [e.g., hermit crabs (*Coenobita brevimanus)*], sea urchins [e.g., purple sea urchin (*Strongylocentrotus purpuratus)*], lobsters [e.g., rock lobster, (*Panulirus ornatus*)], snails [e.g., olive snail (*Oliva sayana*), polychaetes (*Phragmatopoma californica* and *Tetraclita rubescens* found in Central California) (Taylor and Littler 1982), and zebra periwinkle (*Littorina lineolata*)], fish [e.g., striped bass (*Morone saxatilis)* and toadfish (*Tetractenos Hamiltoni)*], and birds [e.g., egrets (*Casmerodius albus)* and ducks (*Somateria spectabilis*)]. Some sessile species (immobile) such as barnacles [e.g., the goose barnacle (*Pollicipes polymerus*, *Balanus* spp., and *Chthamalus* spp.), sponges (*Spinosella* spp.), mussels (*Mytilus edulis*), hydroids, oysters *(Crassostrea virginica)*, and tubicolous polychaetes] live in the non-tidal areas. Currents provide food for these organisms because they are unable to obtain the food themselves (Barnes and Hughes 1988). Mammals, such as sea otters (*Enhydra lutris*), brown bears (*Ursus arctos)*, California sea lions (*Zalophus californianus californianus)*, and Steller sea lions (*Eumetopias jubatus*), also use rocky shorelines for feeding, breeding, and resting areas.

Figure 31. Rocky shore of Lake Michigan in Door County, Wisconsin. Photo courtesy of Karen Rodriguez, United States Environmental Protection Agency, Great Lakes National Program Office.

Figure 32. Rocky shoreline protecting shores from wave action in Gloucester Area, Massachusetts. Photo courtesy of Mary Hollinger, NOAA National Oceanographic Data Center. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/coastline/line0739.htm

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SOFT SHORELINE

Physical Description – Soft shoreline is referred to as unconsolidated shore (Cowardin et al. 1979) which includes sand and mud. Sandy beaches are stretches of land that are covered by loose material (sand) exposed to and shaped by wind or waves (Brown et al. 1990). These beaches and shorelines range from intertidal beaches to mudflats normally comprised of unconsolidated sediment.

Mud and sand flats are usually associated with marine environments, especially where tides expose a large expanse of shore. The flats are exposed to extremely low tides and inundated at high tides with the water table at or near the surface of the substrate. The substrate of mudflats contains organic material smaller in size than sand (EPA 1980). Mud banks form when biologically produced debris is transported by waves allowing accumulation of debris and coverage of a relatively flat, limestone surface. In some areas, mud bank formation may also be influenced during monsoon seasons. Mud banks form barriers that protect the coast from severe erosion and sea water intrusion (Purandara et al. 1996).

Biological Characteristics – These habitats generally lack aquatic macrophytes but are rich in diatoms that provide a major food source for invertebrates and some fishes. On sandy and muddy beaches and flats, the only vegetation consistently present is micro- and macroalgae. However, vegetation can stabilize the supralittoral regions by trapping sand grains to form dunes.

Sand flats also keep conditions moist by absorbing water, producing a suitable environment for some species. When sand flats are completely covered by water, they provide habitat for invertebrates, such as marine worms. Also because water is shallow when covering the sand flats, shore birds are able to obtain food such as small fishes and invertebrates without having to land onto the sand flat.

Soft shorelines provide valuable habitat and feeding grounds, as well as other functions to many organisms including fish, birds, macro- and microinvertebrates, algae, and microbial organisms. These are habitats for beach-nesting birds, burrowing invertebrates, and feeding grounds for wading birds and fish.

Benthic infauna provide food sources for many transient and resident species. Similar to sandy beach habitats, sheltered sand flats are dominated by macro-, meio-, and microfauna. These habitats act as a sink for particles and a source for soluble nutrients.

On the mud shorelines, seaweed, blunt spike rush (*Eleocharis obtu,* mainly on mudflats), bullrush (*Scirpus* spp., found in mud banks), and brown algae (e.g., sea colander) are some of the common vegetative species of the lower intertidal zone. On mud flats, members of the higher trophic levels appear as transients with the tides. At high tide, planktivorous and detritivorous organisms move onto the flats to feed, followed by carnivorous birds and fishes. At low tide, gleaning and probing shorebirds feed on and in the exposed surface while waders seek prey stranded in tidal pools (GBNEP 1994). In all flat habitats, foraging pressure increases as the benthic community increases. Animals such as shorebirds and skates (*Raja* spp.) are able to obtain food by probing the sediment surface or creating localized disturbances to concentrate prey.

Figure 33. Sandy beach in Kauai, Hawaii. Photo courtesy of John Bortniak, NOAA Corps (ret.). Publication of the NOAA Central Library. http://www.photolib.noaa.gov/coastline/line0430.htm

Figure 34. Tidal flats exposed to early morning tide in Dunedin, Florida. Photo courtesy of William Folsom, NOAA National Marine Fisheries Service. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/coastline/line1182.htm

Figure 35. Volunteers making efforts to preserve shoreline by replanting of marsh grass along Chesapeake Bay, Maryland. Photo courtesy of Mary Hollinger, NOAA National Oceanographic Data Center. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/coastline/line2019.htm

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SUBMERGED AQUATIC VEGETATION

Physical Description – Submerged aquatic vegetation (SAV) beds are areas of flowering plants found in shallow, subtidal, or intertidal unconsolidated sediment. SAV is found in areas of clearer water where light penetrates to the sediment surface, yet where water is deep enough to prevent emergent vegetation from becoming established.

SAV beds are complex habitats that allow for high biological productivity. SAV habitats are typically a mixture of open water, rooted SAV, floating leaved plants, and occasionally short emergent vegetation. SAV is physically stable. Plant blades slow water currents and prevent the water column from being vertically well mixed; this increases sedimentation and nutrient uptake.

General Biological Characteristics – The combination of plants depends on water depth, turbidity, and degree of protection from wind and waves (Mitsch and Gosselink 2000; Wilcox 1989). The physical stability, reduced mixing, and shelter of complex SAV habitats provide for a highly productive environment, functioning as nursery areas for fish and invertebrates and as feeding grounds.

In this document, SAV habitats are divided into marine/brackish (salinity 0.5 to 35 ppt) and freshwater (salinity less than 0.5 ppt). Though there are functions, structural components, and parameters common to both, each is introduced separately here.

Figure 36. Seagrass with a jack in the background in the Florida Keys. Photo courtesy of Heather Dine, Florida Keys National Marine Sanctuary. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/sanctuary/sanc0208.htm

Seagrasses (Marine/Brackish)

Physical Characteristics – Marine and brackish SAV, which are largely termed seagrasses, grow on soft sediments of sheltered shallow waters of estuaries, bays, lagoons, and lakes.

Marine/brackish SAV has horizontal underground stems called rhizomes. At intervals along the rhizome are erect shoots that bear the leaves and leaf sheaths. The leaves range in length from a few millimeters to well over a meter. Scars left from old leaves along the rhizome are termed nodes that divide the rhizome into areas called internodes. Roots branch off of these rhizomes. The roots absorb nutrients and help anchor the plants in the substrate (Thayer et al. 1984; Larkhum et al. 1989). This root rhizome structure provides complexity of habitat for infaunal invertebrates (Zieman 1982; Thayer et al. 1984).

Biological Characteristics –SAV is considered among the most productive plant communities in the world (Zieman 1982; Thayer et al. 1984). Adding to this productivity is the organic carbon contribution by epiphytic microalgae that grow abundantly on SAV blades.

However, marine SAV does not typically enter the food web by being eaten directly by herbivores. Once it dies, SAV supports an extensive detritus-based food chain for such organisms as crabs, benthic fish, and others. Decaying SAV also releases nutrients for meiofauna and flora, benthic flora and fauna, epiphytic organisms, plankton, and microbes (Keulen 1999). The herbivores that do feed directly on seagrasses include green sea turtles (*Chelonia mydas*), dugongs (*Dugong dugon*), manatees (*Trichechus manatus*), and a variety of waterfowl.

Most marine taxa tolerate a wide range of salinity, from hypersaline to brackish water. However, their tissues suffer osmotic stress at very low or very high salinity, a condition that may eventually lead to death (Biebl and McRoy 1971). Several lists of the seagrass taxa of the world are available (Thayer et al. 1984; Hemminga and Duarte 2000). Among the most common in the United States are eelgrass (*Zostera marina*), turtle grass (*Thalassia testudinum*), and Cuban shoalgrass (*Halodule wrightii*). Widgeon grass (*Ruppia maritima*) is common to all coasts of the United States, and is found in fresh, brackish, and coastal marine waters.

SAV provides shelter, breeding grounds, and feeding areas for many aquatic organisms such as juvenile fish, shrimp, and benthic invertebrates. Larval and juvenile animals inhabit seagrass beds seasonally, not only to feed but also for protection by the SAV blades from predators (Orth et

al. 1984; Day et al. 1989; Heck et al. 1989; Mattila et al. 1999). For instance, on the eastern and western sides of Florida Bay, large numbers of juvenile spotted seatrout (*Cynoscion nebulosus*) and gray snapper (*Lutjanus griseus*) were reported in seagrass areas where plant densities are high (Chester and Thayer 1990). Other species that inhabit or move into seagrass beds for food and protection include pink shrimp (*Farfantepenaeus duorarum*), blue crabs (*Callinectes sapidus*), bay scallops (*Argopecten irradians*), juvenile cod (*Gadus morhua*), winter flounder (*Pleuronectes americanus*), manatee (*Trichechus manatus*), dugong (*Dugong dugon*), green sea turtles (*Chelonia mydas*), and some waterfowl (Jupp et al. 1996; Lefebvre et al. 1996).

Freshwater

Physical Characteristics – Hydroperiods for this habitat type range from subtidal and intermittently exposed to semi-permanently and seasonally flooded (Cowardin et al. 1979). Similar to emergent vegetation, freshwater SAV is well adapted to the short- and long-term water level fluctuations common with freshwater ecosystems. High water levels eliminate dominant emergent species and provide more space for SAV to grow. Low water levels reduce the dominance of SAV. This combination of high and low water levels in a single location from year to year allows a diversity of plant types to sprout from seed on the exposed sediment, reproduce, and replenish the seed bank (Keddy and Reznicek 1986; Van der Valk and Davis 1978; Wilcox and Meeker 1995).

Freshwater submerged aquatic vegetation (referred to as *aquatic bed* in Cowardin et al. 1979 and also as *SAV*) consists of plants that grow below the surface of the water for most of the growing season in most years. Submerged aquatic vegetation habitats are often a mix of open water, rooted SAV, floating leaved plants, and short emergent vegetation (depending on water depth, turbidity, and degree of protection from wind and waves).

Most of the physical habitat associated with SAV and available to wildlife is provided by the vegetation itself. SAV provides structure for algae and microbes to colonize; invertebrates to graze, hide from predators, and deposit eggs; and fish to spawn, protect young, and feed. SAV also creates a structured canopy, much like a forest, that shades lower portions of the water column, setting up temperature and light availability gradients, thus, vertically diversifying habitats. SAV reduces wave energy and water velocity, causing deposition of fine sediments that would otherwise be eroded (Carpenter and Lodge 1986). SAV also provides important biochemical functions by transporting oxygen to the sediment and in return, transporting nutrients from the sediment into the water column (Wilcox 1995).

Biological Characteristics – Freshwater submergent plants such as muskgrass (*Chara vulgaris*), the pondweeds (*Potamageton* spp.), coontail (*Ceratophyllum demersum*), and naiads (*Najas spp.*) typically dominate submergent communities, providing important feeding and spawning grounds for fish, invertebrates, waterfowl, and diving birds (Mitsch and Gosselink 2000; Wilcox 1995). Clasping-leaved pondweed *(Potamogeton perfoliatus),* sago pondweed *(P. pectinatus)*, curly pondweed *(P. crispus),* wild celery *(Vallisneria americana)*, and horned pondweed (*Zannichella palustris*) also are common freshwater SAV species.

Species of freshwater SAV have significant morphological differences. Several species, such as white and yellow water lilies (*Nymphaea* and *Nuphar* spp.), floating-leaf pondweed (*Potamogeton natans)*, and water shield (*Brasenia schreberi*), are submerged vascular plants with floating leaves

(Cowardin et al. 1979). Other species, such as yellow water lily (*Nuphar luteum*) and water smartweed (*Polygonum amphibium*), have floating leaves, stand erect above the water surface and may be considered short emergents (Cowardin et al. 1979).

Different communities of SAV provide differing habitats; the type and quantity of organisms that can use a particular area depend upon the species diversity, density, and structural aspects of the individual plants. SAV with finely branched foliage maximizes biomass production and habitat structure. Dense SAV beds are often completely devoid of fish and can provide an important refuge for invertebrates to escape predation. Lesser dense beds provide nursery areas for smaller fish by excluding larger fish. Openings in the SAV canopy can be used as cruising lanes for piscivorous fish such as pike (*Esox lucius*) to forage on smaller fish (Wilcox 1995). SAV is also used by a variety of waterfowl as food and foraging areas (Knapton and Scott 1999).

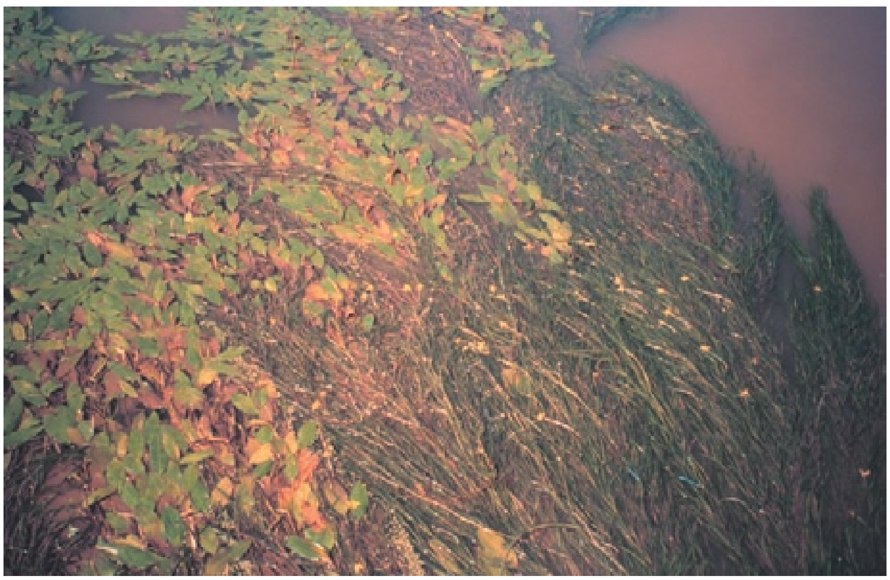

Figure 37. Submerged aquatic vegetation (SAV) within a pond in the Mississippi Delta in Louisiana. Photo courtesy of Terry McTigue, NOAA Office of Response and Restoration. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/coastline/line1211.htm

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MARSHES

Physical Description – Coastal marshes are transitional habitats between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water tidally or seasonally. These coastal areas are influenced by floods, tides, and Great Lakes water level fluctuations. The substrate is predominantly undrained hydric soil (Cowardin et al. 1979). Marshes filter and temporarily store flood water and runoff, mitigating the impacts of floods and helping to improve downstream water quality.

Marshes have salinity levels from saline (approximately 35 ppt) to freshwater (less than 0.5 ppt) further inland. Approximately 70 percent of coastal wetlands of the United States are marine/brackish marshes (Charbreck 1988). Complex topography, such as saltpans, tidal creeks, ridges, and berms characterizes most coastal marshes. In tidal rivers, salinity gradients occur due to the mixing of freshwater with saltwater.

Great Lakes coastal wetlands are dominated by the hydrologic processes of the Great Lakes, including waves, wind tides, and seasonal and long-term water level fluctuations. These processes determine the vegetation communities and structural complexity of the marshes along Great Lake's shorelines.

General Biological Characteristics – The defining structural feature of marshes is the presence of upright, emergent plants (e.g., cattails, grasses, and sedges) that can live all or part of the time with their roots submerged (Cowardin et al. 1979).

In salt marshes, the flora and fauna have adapted to the stresses of salinity, periodic tidal inundation, exposure to air, and temperature fluctuations. Vegetation is adapted to lower salinity in some areas. In the Great Lakes, flora and fauna have adapted to periodic water level fluctuations resulting from seiches or changes in the water levels of the lakes themselves. Both marine and Great Lakes marshes provide spawning and nursery habitat and feeding grounds for numerous species of mammals, fish, waterfowl, migratory birds, reptiles, amphibians, and invertebrates. Coastal marshes of either type are among the most productive habitats on Earth.

In this manual, marshes are divided into two categories: marine/brackish (salinity 0.5 - 35 ppt) and freshwater (salinity less than 0.5 ppt).

Marine/Brackish

Physical Characteristics – Marine and brackish marshes are composed of a mix of open water and vegetated areas, including short and tall salt marsh grasses and other plants. These are divided into zones based on elevation. Plant community composition is highly influenced by slight differences in elevation. Therefore, slope and elevation are defining aspects of the habitat.

Biological Characteristics – Coastal marshes include plants that are adapted to salty or brackish water. Common plant taxa along the continental United States include cordgrass (*Spartina* spp), dominant in low intertidal zones, and needlerush *(Juncus* spp*.),* dominant in upper intertidal areas. Some other vegetative species include spike grass (*Distichlis spicata*), salt marsh plantain (*Plantago maritima*), cattail (*Typha latifolia*), common reed (*Phragmites australis*), and saltwort (*Batis maritima*).

Macroalgae is an important primary producer in marine/brackish marshes, occurring on the sediment surface and attached to the lower portion of the emergent vascular plants. Macroalgae is a seasonal and ephemeral portion of the marsh community. Macroalgae can contribute to annual variability of oxygen concentrations by producing oxygen during growth, then consuming it as bacteria break down the decaying remains after the plants die back. Inputs from intertidal macroalgae and marsh microalgae contribute to the organic matter that support invertebrates, fish, and shorebirds such as the light-footed clapper rail (*Rallus longirostris levipes*) (Kwak and Zedler 1997).

Marine/brackish marsh habitat provides food, protection from predation and an abundance of niches for fish, waterfowl, and other animal species. The lifecycles of animals using brackish and marine marshes are keyed to the seasonal patterns within the habitat, including variation in temperature, water level, salinity, and food availability. Transient species (aquatic, terrestrial, and avian) use marsh habitat as feeding and resting areas during migrations. These transients receive benefits from the marsh habitat and can contribute to the lifecycles of other species in the area. For instance, birds assist in dispersing propagules of various marsh plants (Stout 1984). Some birds found in brackish or marine marshes include the California least tern (*Sterna antillarum browni*), great blue heron (*Ardea herodias*), clapper rails (*Rallus longirostris obsoletus*), snowy egret (*Egretta thula*), marsh wren (*Cistothorus palustris*), Canada geese (*Branta canadensis*), and tundra swans (*Cistothorus columbianus)*.

Other mobile species occupying marshes include fish and crustaceans, such as blue crab (*Callinectes sapidus*), lined shore crab (*Pachygrapsus crassipes*), yellow shore crab (*Hemigrapsus oregonensis*), white shrimp (*Litopenaeus setiferus*), brown shrimp (*Farfantepenaeus aztecus*), flounder (e.g., *Paralichthyes* spp.), mullet (*Mugil* spp.), spotted seatrout (*Cynoscion nebulosus*), and red drum (*Sciaenops ocellatus*). Diamondback terrapins (*Malaclemys terrapin*) are found in both saline and brackish marshes. Mammals inhabiting these habitats include mink (*Mustela vison*), weasel (*Mustela frenata*), swamp rabbit (*Sylvilagus aquaticus*), lemming (*Lemmus trimucronatus*), rice rat (*Oryzomys palustris*), and muskrat (*Ondatra zibethicus)*. Larger mammals, such as wolves (*Canis lupus*), bears (*Ursus* spp.), and feral horses (*Equus caballus*) can seasonally use coastal marshes as feeding grounds.

Figure 38. Sapelo Island, Georgia. Black needle rush (*Juncus*) in the far left corner of photo and Saltmarsh cordgrass (*Spartina*) on both sides of the stream. Photo courtesy of Sapelo Island National Estuarine Research Reserve. Publication of the NOAA National Oceanic and Atmospheric Administration Central Library. http://www.photolib.noaa.gov/coastline/line0926.htm

Freshwater

Physical Characteristics – As with saline/brackish marshes, freshwater marshes are characterized by erect, herbaceous hydrophytes, rooted in soft substrates, typically extending above the water surface. All water regimes can occur except subtidal and irregularly exposed (Cowardin et al. 1979).

Biological Characteristics – Marsh vegetation supplies the habitat structure for invertebrates, fish, and other wildlife (Mitsch and Gosselink 2000). Marsh vegetation is also well adapted to short- and long-term water level fluctuations characteristic of freshwater systems. If water levels rise and remain high long enough, woody vegetation along marsh edges may be killed off and herbaceous, emergent plant species come to dominate. Eventually, when water levels fall woody species may once again become established. If water levels fall low enough, SAV can be eliminated from areas in which it was once dominant, sediments are exposed, seed banks germinate, and emergent plant species become established (Keddy and Reznicek 1986). In essence, marshes move horizontally, back and forth across the permanent water/terrestrial interface with vertical water level fluctuations (Minc 1997).

Cowardin et al. (1979) subdivides freshwater marshes into persistent and non-persistent types based on the difficulty with which the dominant vegetation is decomposed and nutrients cycled back into the system. Persistent marshes are dominated by species that normally remain standing at least until the beginning of the next growing season. Persistent marshes are often dominated by narrow-leaved cattail (*Typha angustifolia*), sedges (*Carex* spp.), common reed (*Phragmites australis*), and southern wild rice (*Zizaniopsis miliacea*). There is also a variety of broad-leaved persistent species common to these systems such as purple loosestrife (*Lythrum salicaria*, an invasive species), dock (*Rumex mexicanus*), and waterwillow (*Decodon verticillatus*).

In non-persistent marshes, there may be no obvious sign of emergent vegetation at certain times of the year due to the quick decay rate. Vegetation in non-persistent marshes is related to the seasonal succession of vegetation emergence. For example, wild rice (*Zizania aquatica*) does not become apparent in some coastal marshes until midsummer and fall, when it may form dense stands. Non-persistent emergents also include arrow arum (*Peltandra virginica*), pickerelweed (*Pontederia cordata*), arrowheads (*Sagittaria* spp.), and many species of smartweeds (*Polygonum* spp.). Unlike persistent marsh species, these plants quickly decompose upon senescence and return accumulated nutrients and carbon back to the water column, often within a few days or weeks.

Figure 39. Freshwater marsh near Ridgetown Ontario, Canada. Photo courtesy of Romy Myszka, United States Department of Agriculture, Natural Resources Conservation Service. http://www.epa.gov/glnpo/image/viz_nat1.html

Marsh habitats provide a variety of necessary habitats for fish, waterfowl, and other wildlife (Mitsch and Gosselink 2000). Freshwater fishes use marsh areas during high water periods for feeding, spawning, and nursery areas. The high stem densities typical of marshes provide excellent cover for young fish and small invertebrates to feed on algae and one another while escaping predation from larger fish and wading birds. Canada geese and some ducks feed on the tender shoots of emergent vegetation. Wading and songbirds use marshes as critical feeding

Figure 40. Great Lakes coastal marsh dominated by cattails with adjacent floating leaved plants and open water areas allowing fish and waterfowl access to all three habitats. Photo courtesy of Doug Wilcox, USGS.

areas along migration routes or as seasonal destinations. Though many species of mammals use marshes, nutria (*Myocastor coypus*) and muskrat (*Ondatra zibethicus*) are dependent upon them to provide the majority of their habitat needs.

Nutria is an invasive species and causes extensive and permanent damage to marshes while foraging for food. Muskrats too, can denude marshes of vegetation but typically do not cause as much structural damage as nutria. There are also some beneficial aspects to muskrat foraging. At some point in their succession, freshwater marshes often become dominated by cattails. Muskrats feed voraciously on cattails, clearing the marsh of vegetation, opening it up for waterfowl use. In the process, they pile the unused portions of the cattails into large piles (feeding stations). Once the marsh is depleted of edible vegetation, ducks and geese can use feeding stations as nesting spots safe from predation. Feeding stations also provide topographic diversity to the marsh basin. This allows a greater diversity of plant species to establish (Weller 1994).

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MANGROVE SWAMPS

Physical Description – Mangrove swamps are dominated by mangrove trees that live between the sea and the land in areas that are inundated by tides. Mangroves thrive along protected shores with fine-grained sediments where the mean temperature during the coldest month is greater than 20º C, which limits their northern distribution.

Mangroves are found throughout the Caribbean and Pacific, as well as in coastal Louisiana, Texas, and Florida. (Mitsch and Gosselink 2000). The most northern occurring black mangroves (*Avicennia germinans*) are found on the barrier islands of Louisiana. In both Texas and Louisiana, mangroves occur in a shrub-like form.

Biological Characteristics – Mangroves are salt-tolerant woody plants. They have adapted to survive high salinity, occasional harsh temperatures, and anoxic soils, forming unique communities known as mangals or mangrove forests along shorelines (Chapman 1976; Teas 1984) These habitats are frequently placed in the following classes: fringe, riverine, basin, and dwarf or scrub mangroves (Mitsch and Gosselink 2000).

Mangrove species occurring in the United States include black mangrove, red mangrove (*Rhizophora mangle*), and white mangrove (*Laguncularia racemosa*) (Massaut 1999). The restoration strategies for these three species will differ, based on their physical characteristics and tolerances. Red mangroves have distinct prop roots that are tangled and reddish, and aerial roots that originate from the trunk and branches. Black mangroves are recognized by their root projections, called pneumatophores that project from the soil around the tree's trunk. They are found in slightly higher elevations than red mangroves (Jimenez and Lugo 1985). White mangrove trees have no visible aerial root system and are located mainly in elevations higher and farther upland than the red or black mangroves.

Mangroves support many terrestrial and aquatic fauna and flora like birds, mammals, crustaceans, and fish, and a diverse understory (Lugo and Snedaker 1974). The mangrove prop roots disperse wave energy, increase surface area for organisms such as sponges and mollusks, and provide shelter for marine organisms such as the gray snapper (*Lutjanus griseus)*, spotted seatrout (*Cynoscion nebulosus*), and red drum (*Sciaenops ocellacurema*) (recreational fish seen in Florida mangrove systems). However, in Florida the most abundant fish species among red mangrove prop roots include fishes of the silverside, killifish, mojarras, anchovy, and gobi families (Thayer and Sheridan 1999).

Mangrove roots anchor trees firmly in the soft mud and allow sufficient oxygen to reach the base of the tree. The above ground component of the root system is porous and provides oxygen to the lower submerged and buried portion for respiration. New prop roots grow from branches that project over the water (Hogarth 1999).

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Figure 41. Mangroves showing root system below the water surface. Photo courtesy of NOAA Corps Collection. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/corps/corp2269.htm

Figure 42. Red mangrove with prop roots located in John Pennekamp State Park, Florida. Photo courtesy of Richard B. Mieremet, NOAA Office of Sustainable Development and Intergovernmental Affairs. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/coastline/line0008.htm

DEEP WATER SWAMPS

Physical Description – Deepwater swamps are forested wetlands that develop along edges of lakes, in alluvial river swamps, in slow-flowing strands, and in large, coastal-wetland complexes. They can be found along the Atlantic and Gulf Coasts and throughout the Mississippi River valley from Louisiana to southern Illinois. They are distinguished from other forested swamps by the tolerance of the dominant vegetation to prolonged flooding (Mitsch and Gosselink 2000).

Though once common throughout the southeastern United States, only a small portion of the original deepwater swamps remains (Allen et al. 2001; Wharton et al. 1982). Historically, losses were due to extensive logging but recently altered hydrology, herbivory from exotic nutria, saltwater intrusion, and sea level rise have further reduced acreage (Allen et al. 1996; Conner and Toliver 1990; Myers et al. 1995; Sklar 1985).

The soils of cypress swamps range from mineral to accumulated peat depending on the hydrodynamics and topography of the specific system (Bondavalli et al. 2000; Giese et al. 2000). In some swamps, floating logs and tree stumps provide the only substrate for understory vegetation and regeneration of overstory species. Deepwater swamps that are continually flooded and have high nutrient concentrations may develop thick mats of duckweed (e.g., *Lemna* spp., *Spirodela* spp., or *Azolla* spp.) (Mitsch and Gosselink 2000).

Deepwater swamps are essential to the health and functioning of downstream areas. Swamps associated with alluvial systems allow floodwaters to spread out and deposit suspended sediment loads. They also absorb and transform nutrients in floodwaters, helping prevent eutrophication of receiving water bodies (Mitsch and Gosselink 2000).

Biological Characteristics – Bald cypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), and black gum (*N. sylvatica*) are the dominant tree species of these habitats. Adult cypress and tupelo can survive permanent inundation, although seedlings require exposed sediment in order to germinate and become successfully established (Keeland et al. 1997; Middleton 2000; Schneider and Sharitz 1988).

The presence and abundance of understory vegetation depend upon both the amount of light penetrating the canopy and the local flooding regime. Some areas with open canopies and moderate flooding have a diverse shrub layer [e.g., buttonbush (*Cephalanthus occidentalis*), swamp-privet (*Forestiera acuminata*), and water-elm (*Planera aquatica*)] (Conner and Buford 1998). Other swamps, with closed canopies or longer flooding times, may be devoid of any ground layer vegetation.

Deepwater swamps support a diversity of wildlife. Macroinvertebrates (crawfish, shrimp, insects, clams, snails, and worms) are commonly found in deepwater swamps (Sklar 1985; Thorp et al. 1985). Fish can be temporary or permanent residents. While flooded, these areas provide spawning, nursery, and foraging habitats. Reptiles and amphibians, too, are often found in deepwater swamps (Mitsch and Gosselink 2000). Nutria, an exotic rodent, is common to deepwater swamp habitats. They graze heavily on the roots and shoots of newly planted or germinating trees and are one of the major obstacles to successful reforestation efforts (Llewellyn and Shaffer 1993; Myers et al. 1995).

Figure 43. Deepwater swamp in the Atchafalaya basin, Louisiana. Photo courtesy of Aaron Podey, Louisiana State University.

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RIVERINE FORESTS

Physical Description – Riverine forests are wetlands dominated by trees and usually found along sluggish streams, drainage depressions, and in large alluvial floodplains (Mitsch and Gosselink 2000). In winter and spring, riverine forests can flood with a meter or more of water but by late summer, water levels in most cases recede and expose the soil (Wharton et al. 1982). Soils are typically mineral though limited peat accumulation may occur in deeper depressions and wetter areas (Giese et al. 2000).

Riverine forests are essential to the health and functioning of downstream areas. These forested wetlands allow floodwaters to spread out, slow water down, reduce flood peaks, and deposit suspended sediment loads. They also absorb and transform nutrients in floodwaters, preventing eutrophication of receiving bodies of water (Conner and Day 1982; Giese et al. 2000; Gilliam 1994; Osborne and Kovacic 1993; Stanturf et al. 2000).

Biological Characteristics – Riverine forests are extremely diverse communities, exhibiting a variety of canopy/ground cover combinations influenced by the hydrodynamics of the associated river (Gregory et al. 1991). Dominant woody vegetation may include bald cypress (*Taxodium distichum*), cottonwoods (*Populus* spp.), green ash (*Fraxinus pennsylvanica*), silver and red maple (*Acer saccharinum and A. rubrum,* respectively), and a variety of oaks (*Quercus* spp.) (Allen et al. 2001; Barnes and Wagner 1981; Mitsch and Gosselink 2000). The presence and abundance of understory vegetation depend upon the amount of light that penetrates the canopy and the local flooding regime. Some areas with open canopies and moderate flooding may have a diverse shrub and herbaceous ground flora. Others, with closed canopies or longer flooding times may be devoid of any ground layer vegetation (Mitsch and Gosselink 2000).

Riverine forests support a variety of wildlife. Many species of macroinvertebrates (crawfish, shrimp, insects, clams, snails, and worms) can be found in riverine forests (Bowers et al. 2000; Wharton et al. 1982). Fish make extensive use of flooded and backwater areas as spawning, nursery, and foraging grounds (Killgore and Hoover 1992; Wharton et al. 1982). Mammals such as

white-tailed deer (*Odocoileus virginianus*), nutria, rabbits (e.g., the Eastern cottontail, *Sylvilagus floridanus*), beaver (*Castor canadensis*), and mink (*Mustela vison*), as well as migrating songbirds, waterfowl, and wading birds all can commonly be found in riverine forest habitats (Guilfoyle 2001; O'Neal et al. 1992; Wharton et al. 1982).

Figure 44. A riverine forest in spring. High flows from snowmelt and rain have flooded the forest floor. Photo courtesy of Eric Thobaben, Michigan State University.

Figure 45. A riverine forest in late summer. Summer river flows are much lower than those in spring, the forest floor is dry allowing herbaceous vegetation to grow. These two seasonal views are of a riverine forest adjacent to the Kalamazoo River, Lower Michigan. Photo courtesy of Eric Thobaben, Michigan State University.

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APPENDIX II: MATRICES OF HABITAT CHARACTERISTICS AND PARAMETERS

When developing a restoration monitoring plan, the goals of the project and knowledge of the habitat should be used to identify potential structural and functional characteristics to be monitored. Parameters then need to be identified that can be used to appropriately determine the status of or change in each characteristic.

In some cases, it is critical to monitor the effects a restoration project has on social or economic aspects of the local human community or regional population. The parameters presented in this appendix and elsewhere in this volume, however, do not address socioeconomics. The monitoring of the effects of coastal restoration on human dimensions will be covered in *Volume Two: Tools for Monitoring Coastal Habitats*. Additionally, a stand-alone document addressing in detail the role of socioeconomics in the monitoring of coastal restoration projects is currently in development.

Through a series of matrices, this appendix establishes a three-part process that walks the reader through the selection of habitat characteristics and corresponding parameters for inclusion in a restoration monitoring plan. The three steps are: identification of appropriate structural and functional characteristics of the habitat; identification of parameters that determine the change in or status of those habitat characteristics; and determination of suitability of the potential parameters for use in a given habitat. An example of how to use this appendix follows the description of the matrices.

In using these matrices, it should be remembered that the goal of coastal restoration is to recover functioning habitat as noted earlier in this document in *The Process of Developing a Monitoring Plan.*

Matrix A. Structural and Functional Characteristics of the Habitats

The structural components of a habitat are the physical, chemical, and biological characteristics that define that habitat. The functional components are the processes occurring within and between habitats as a result of their structural components. The ultimate goal of any restoration action should be to return functions and not simply build structure[6]. Understanding the structure and function of a habitat allows for an understanding of the fundamental ecology of the system and selection of those parameters most relevant to the goals of the project.

Matrix A provides a listing of significant structural and functional characteristics for each habitat type. This listing was developed through searches of the ecological literature, published restoration efforts, and ecological monitoring studies. Additionally, ecologists, restoration researchers, and people involved with monitoring provided extensive input. Other characteristics not included on these lists may be appropriate depending on the goals of an individual restoration project. The determination of which structural and functional characteristics will be monitored for a given restoration project should be made in conjunction with experts on the local habitat, keeping in mind that the goals of a given project that directly determines the characteristics to be monitored.

Detailed habitat descriptions, as well as discussions of the habitat structural and functional characteristics and the rationale for their inclusion, are found in *Coastal Habitats: Ecology, Restoration, and Monitoring*, a chapter in *Volume Two: Tools for Monitoring Coastal Habitats*.

Matrix B. Structural and Functional Characteristics and Their Associated Parameters

Once a list of the relevant structural and functional characteristics to be monitored has been developed for a restoration project, parameters need to be identified that will appropriately determine the status of or change in those characteristics.

Matrix B provides a list of parameters associated with each structural and functional characteristic identified in Matrix A. The experts in each habitat reviewed and augmented the lists to ensure that parameters included can be used to accurately assess progress toward restoration goals. Additionally, searches of the ecological literature, published restoration efforts, and ecological monitoring studies were conducted to determine the types of parameters considered in coastal restoration projects. Matrix B should be used to develop a broad list of potential parameters that may be included in the monitoring plan. This list of potential parameters is not exhaustive, however, and should be considered a starting point. Other parameters not included on these lists may be appropriate for assessing change in or the status of a given characteristic. The determination of the parameters to be monitored should be made in conjunction with experts, including those with a background in statistics, the local habitat, and monitoring the characteristics in question.

Matrix C. Restoration Monitoring Parameters By Habitat

Once a broad list of monitoring parameters has been developed, it is important to review that list to determine those parameters that are applicable to a specific habitat. Matrix C provides a list of parameters that are significant or appropriate for monitoring in each habitat. The parameters have been sorted to reflect their relevance to either structural or functional characteristics.

As with Matrices B and C, the listing of habitat specific parameters used in restoration monitoring was developed through literature searches of restoration efforts and ecological monitoring studies and through extensive input from restoration and monitoring researchers with expertise in that particular habitat. The lists include those parameters most commonly measured in restoration monitoring in each habitat and are not to be considered exhaustive. Experts on each habitat have reviewed and augmented the lists to ensure that parameters included can be used to accurately assess progress toward restoration goals. Other parameters not included on these lists may be appropriate depending on the goals of an individual restoration project.

The parameters included in this matrix are classified into two groups. Parameters marked with a filled circle are those indicated by experts as critical for inclusion in the monitoring of most restoration projects in this habitat. Parameters marked by an open circle are those that may be considered for inclusion in a monitoring plan, depending on the goals of the restoration project but are not considered critical for all monitoring projects.

How to Use the Matrices

The example provided below walks readers through the process of identifying potential parameters to be measured in the monitoring of a coastal restoration project. Although most projects will have multiple goals, this example will pertain to a single goal.

Project goal: To increase the acreage of marsh habitat within the project area as a means of supporting an endangered terrapin population.

Matrix A: There are a wide variety of structural and functional characteristics associated with marshes. When reading through this list, the intent and constituent parts of the specific goal should be kept in mind. Given that the goal above involves creating marsh with the specific idea of supporting terrapins, the long list of characteristics can be reduced to these items:

- Habitat created by plants
- Provides breeding grounds
- Provides nursery area
- Provides feeding grounds
- Supports a complex trophic structure
- Supports biomass production

Matrix B: For each characteristic identified in Matrix A, a set of potential parameters is then identified. This example walks through the parameter selection process for one of the characteristics from the above list. The long list of parameters generated in this step of the process will be tailored to the habitat in question through the use of Matrix C and knowledge of the intent of the specific goal.

Parameters associated with the functional characteristic "Provides feeding grounds":

Geographical

- Acreage of habitat types

Biological

Plants

- Species, composition, and % cover of:
  - o Algae
  - o Epiphytes
  - o Herbaceous vascular
  - o Invasives
  - o Woody
- Canopy extent and structure
- Interspersion of habitat types
- Litter fall
- Mast/seed production
- Phytoplankton diversity and abundance
- Plant health (herbivory damage, disease)
- Plant weight (above and/or below ground parts)
- Woody debris (root masses, stumps, logs)

Animals

- Species, composition, and abundance of:
  - o Amphibians
  - o Birds
  - o Fish
  - o Invasives
  - o Invertebrates

    - Mammals
    - Reptiles
- Coral growth rate
- Coral recruitment and survivorship
- Vertical relief of reef

Hydrological

Physical
- Trash
- Water level fluctuation over time

Chemical
- Chlorophyll concentration
- Salinity (in tidal areas)
- Toxics

Soil/Sediment

Physical
- Basin elevations
- Geomorphology (slope, basin cross section)

Chemical
- Organic content in sediment

Matrix C: This matrix assists readers in reducing the long list of potential parameters down to those appropriate for the habitat and goal in question.

Using Matrix C and knowledge of terrapin biology, the list of parameters for the functional characteristic "provides feeding grounds" becomes:

- Acreage of habitat types (associated with the structural element of the goal)
- Interspersion of habitat types (allows access to marsh habitat)
- Herbaceous species composition and percent cover (type and density of marsh plants is one aspect of the quality of the habitat)
- Species composition and abundance of:
    - Fish (potential prey items)
    - Invertebrates (potential prey items)
    - Reptiles (terrapins)
- Water fluctuation over time (important for marsh health, as well as aspects of terrapin biology including breeding and feeding)
- Basin elevations (important aspect of habitat quality and accessibility)
- Geomorphology, including slope and cross section (important for marsh diversity and accessibility)

This process provides a convenient means of identifying habitat characteristics and their associated parameters. It is critical, however, that the process be augmented with a thorough knowledge of local habitats and a strong understanding of the intent of the project goals. Use the characteristics and parameters identified through the use of these matrices as a starting point for discussion for a group that includes managers, statisticians, and scientists such as ecologists, hydrologists, geologists, physical oceanographers, and fisheries biologists.

Matrix A: Structural and Functional Characteristics of the Habitats

	Habitats												
Structural Characteristics	Water Column	Rock Bottom	Coral Reef	Oyster Reef	Soft Bottom	Kelp and Macroalgae	Rocky Shore	Soft Shore	SAV	Marsh	Mangroves	Deepwater Swamps	Riverine Forests
Biological													
Habitat created by animals			x	x									
Habitat created by plants[1]						x			x	x	x	x	x
Physical													
Sediment grain size		x		x	x	x	x	x	x	x	x	x	x
Topography/Bathymetry		x	x	x	x		x	x	x	x	x	x	x
Turbidity	x					x			x				
Hydrological													
Current velocity	x	x		x	x	x	x		x	x	x	x	
Tides/Hydroperiod[2]	x			x	x	x	x	x	x	x	x	x	x
Water sources	x	x	x	x	x	x			x	x	x	x	x
Wave energy	x	x	x	x	x	x	x	x	x	x	x		
Chemical													
Nutrient concentration	x		x	x					x	x	x		
pH, salinity, toxics, redox, DO	x	x	x	x	x	x	x		x	x	x	x	x
Functional Characteristics													
Biological													
Contributes to primary productivity	x					x		x	x	x	x	x	x
Exhibits symbiotic species interactions			x										
Produces wood											x	x	x
Provides breeding grounds	x	x	x	x	x	x	x	x	x	x	x	x	x
Provides feeding grounds	x	x	x	x	x	x	x	x	x	x	x	x	x
Provides nursery areas		x	x	x		x			x	x	x	x	x
Provides refuge from predation		x	x	x		x	x	x	x	x	x		
Provides substrate for attachment		x	x	x		x	x		x	x	x		
Supports a complex trophic structure			x	x		x			x	x	x	x	x
Supports biodiversity			x	x		x			x	x	x		
Supports biomass production	x		x	x		x			x	x	x	x	x
Hydrological													
Physical													
Affects transport of suspended/dissolved material	x	x							x	x	x	x	x
Alters turbidity		x		x	x			x	x	x	x	x	x
Modifies water temperature									x		x	x	x
Provides temporary flood water storage										x	x	x	x
Reduces erosion potential		x	x	x		x	x		x	x	x	x	
Reduces wave energy		x	x	x		x	x		x	x	x		
Chemical													
Modifies chemical water quality	x			x	x	x			x	x		x	x
Modifies dissolved oxygen					x	x			x				
Supports nutrient cycling	x		x	x	x	x			x	x	x	x	x

[1] When present, plants are always important even if they are not a defining structural feature of the habitat.
[2] Refers to the timing, height, and duration of water level fluctuations
X = a defining structural or functional characteristic of a particular habitat

Matrix B: Parameters to Monitor Structural and Functional Characteristics

Structural Characteristics

Parameters to Monitor	Biological: Habitat created by animals	Biological: Habitat created by plants	Physical: Sediment grain size	Physical: Topography Bathymetry	Physical: Turbidity	Hydrological: Current velocity	Hydrological: Tides Hydroperiod	Hydrological: Water Sources	Hydrological: Wave energy	Chemical: Nutrient concentration	Chemical: pH, salinity, toxics, redox, DO[1]
Geographical											
Acreage of habitat types	◆	◆			◆						
Biological											
Plants											
Species, composition, and % cover of:											
Algae		◆									
Epiphytes		◆									
Herbaceous vascular		◆									
Woody		◆									
Basal area		◆									
Canopy extent and structure[2]		◆									
Interspersion of habitat types	◆	◆		◆							
Phytoplankton diversity and abundance		◆			◆					◆	
Plant height		◆									
Seedling survival		◆									
Stem density		◆									
Woody debris (root masses, stumps, logs)		◆		◆							
Animals											
Vertical relief	◆			◆							
Hydrological											
Physical											
Chlorophyll concentration					◆						
PAR[3]					◆						
Secchi disc depth					◆						
Shear force at sediment surface						◆			◆		
Sheet flow						◆					

[1] Dissolved oxygen
[2] Applies to forest, submerged aquatic vegetation (SAV), and kelp habitats
[3] Photosynthetically active radiation, measured at canopy height and substrate surface

◆ = a pairing between a habitat characteristic and a measured parameter

Matrix B: Parameters to Monitor Structural and Functional Characteristics (cont.)

Parameters to Monitor	Structural Characteristics										
	Biological		**Physical**			**Hydrological**				**Chemical**	
	Habitat created by animals	Habitat created by plants	Sediment grain size	Topography Bathymetry	Turbidity	Current velocity	Tides Hydroperiod	Water Sources	Wave energy	Nutrient concentration	pH, salinity, toxics, redox, DO
Hydrological (cont.)											
Physical (cont.)											
Temporary water							◆				
Temperature							◆	◆			
Upstream land use								◆			
Water column current velocity						◆					
Water level fluctuation over time							◆	◆			
Chemical											
Dissolved oxygen											◆
Groundwater indicator chemicals[4]								◆			
Nitrogen and phosphorus										◆	
pH											◆
Salinity (in tidal areas)							◆	◆			◆
Silicon										◆	
Toxics								◆			◆
Soil/Sediment											
Physical											
Basin elevations				◆							
Bulk density			◆								
Depth of mottling							◆				
Geomorphology (slope, basin cross section)				◆			◆				
Moisture levels and drainage							◆				
Organic content			◆				◆			◆	
Percent sand, silt, and clay			◆							◆	
Sedimentation rate and quality			◆	◆		◆	◆			◆	
Chemical											
Pore water nitrogen and phosphorus										◆	
Pore water salinity (in tidal areas)											◆
Redox potential											◆

[4] Calcium and magnesium

◆ = a pairing between a habitat characteristic and a measured parameter

Matrix B: Parameters to Monitor Structural and Functional Characteristics (cont.)

Parameters to Monitor	Functional Characteristics: Biological											Physical						Chemical		
	Contributes primary production	Exhibits symbiotic species interactions	Produces wood	Provides breeding grounds	Provides feeding grounds	Provides nursery areas	Provides refuge from predation	Provides substrate for attachment	Supports a complex trophic structure	Supports biomass production	Supports biodiversity	Affects transport of suspended/dissolved material	Alters turbidity	Modifies water temperature	Provides temporary floodwater storage	Reduces erosion potential	Reduces wave energy	Modifies chemical water quality	Modifies dissolved oxygen	Supports nutrient cycling
Geographical																				
Acreage of habitat types	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
Biological																				
Plants																				
Species, composition, and % cover of:																				
Algae	◆	◆		◆	◆	◆	◆	◆	◆	◆	◆	◆	◆			◆	◆	◆	◆	◆
Epiphytes	◆	◆			◆				◆	◆	◆	◆							◆	◆
Herbaceous vascular	◆			◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆		◆	◆	◆	◆	◆
Invasives				◆	◆	◆	◆		◆		◆									
Woody	◆		◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆			◆
Basal area	◆		◆							◆										
Canopy extent and structure[5]			◆	◆	◆	◆	◆	◆		◆	◆	◆	◆	◆			◆			
Interspersion of habitat types				◆	◆	◆	◆		◆	◆	◆	◆	◆	◆	◆	◆	◆	◆		◆
Litter fall	◆				◆				◆	◆			◆							◆
Mast/seed production	◆				◆					◆										
Phytoplankton diversity and abundance	◆				◆				◆	◆	◆		◆					◆	◆	◆
Plant health (herbivory damage, disease[6])					◆															
Plant height	◆									◆				◆						
Plant weight (above and/or below ground parts)	◆		◆		◆					◆										
Nutrient levels in algal tissues (N and P)																		◆		◆
Rate of canopy closure	◆		◆							◆				◆						

[5] Applies to forest, submerged aquatic vegetation, and kelp habitats
[6] If the whole community is destroyed by disease or lack of seedling survival, all vegetation-related functions will be impaired

◆ = a pairing between a habitat characteristic and a measured parameter

Matrix B: Parameters to Monitor Structural and Functional Characteristics (cont.)

Functional Characteristics

Parameters to Monitor	Biological: Contributes primary production	Exhibits symbiotic species interactions	Produces wood	Provides breeding grounds	Provides feeding grounds	Provides nursery areas	Provides refuge from predation	Provides substrate for attachment	Supports a complex trophic structure	Supports biomass production	Supports biodiversity	Physical: Affects transport of suspended/dissolved material	Alters turbidity	Modifies water temperature	Provides temporary floodwater storage	Reduces erosion potential	Reduces wave energy	Chemical: Modifies chemical water quality	Modifies dissolved oxygen	Supports nutrient cycling
Biological (cont.)																				
Plants (cont.)																				
Seedling survival[7]			◆													◆				
Stem density						◆	◆	◆	◆			◆	◆	◆		◆	◆			
Woody debris (root masses, stumps, logs)			◆	◆	◆	◆	◆	◆	◆		◆					◆	◆			
Biological																				
Animals																				
Species, composition, and abundance of:																				
Amphibians				◆	◆	◆	◆		◆	◆	◆									
Birds				◆	◆	◆	◆		◆	◆	◆									
Fish				◆	◆	◆	◆		◆	◆	◆									
Invasives					◆	◆	◆			◆	◆	◆	◆							
Invertebrates				◆	◆	◆	◆		◆	◆	◆									
Mammals				◆	◆	◆	◆		◆	◆	◆									
Reptiles				◆	◆	◆	◆		◆	◆	◆									
Coral growth rate	◆	◆		◆	◆	◆	◆	◆	◆	◆	◆	◆	◆							
Coral recruitment and survivorship	◆	◆		◆	◆	◆	◆	◆	◆			◆	◆							
Fecal coliforms																		◆	◆	
Grazer density	◆					◆	◆													
Vertical relief of reef	◆			◆	◆	◆	◆	◆	◆			◆	◆			◆	◆			

[7] If the whole community is destroyed by disease or lack of seedling survival, all vegetation-related functions will be impaired

◆ = a pairing between a habitat characteristic and a measured parameter

Matrix B: Parameters to Monitor Structural and Functional Characteristics (cont.)

Parameters to Monitor	Functional Characteristics: Biological											Physical						Chemical		
	Contributes primary production	Exhibits symbiotic species interactions	Produces wood	Provides breeding grounds	Provides feeding grounds	Provides nursery areas	Provides refuge from predation	Provides substrate for attachment	Supports a complex trophic structure	Supports biomass production	Supports biodiversity	Affects transport of suspended/dissolved material	Alters turbidity	Modifies water temperature	Provides temporary floodwater storage	Reduces erosion potential	Reduces wave energy	Modifies chemical water quality	Modifies dissolved oxygen	Supports nutrient cycling
Hydrological																				
Physical																				
Fetch												◆	◆			◆	◆		◆	
PAR	◆									◆		◆	◆							
Secchi disc depth	◆									◆		◆	◆							
Shear force at sediment surface												◆	◆			◆	◆			
Sheet flow												◆	◆		◆	◆		◆	◆	◆
Temperature				◆		◆								◆				◆	◆	
Temporary water															◆			◆	◆	◆
Trash					◆							◆	◆							
Upstream land use												◆	◆					◆		
Water column current velocity												◆	◆			◆				
Water level fluctuation over time				◆	◆	◆	◆					◆	◆		◆	◆			◆	◆
Chemical																				
Chlorophyll concentration	◆				◆					◆		◆	◆					◆	◆	◆
Dissolved oxygen				◆		◆			◆		◆							◆	◆	◆
Nitrogen and phosphorus	◆									◆			◆					◆		◆
pH																		◆		
Salinity (in tidal areas)				◆	◆						◆							◆	◆	

◆ = a pairing between a habitat characteristic and a measured parameter

Matrix B: Parameters to Monitor Structural and Functional Characteristics (cont.)

	Functional Characteristics																			
	Biological											**Physical**						**Chemical**		
Parameters to Monitor	Contributes primary production	Exhibits symbiotic species interactions	Produces wood	Provides breeding grounds	Provides feeding grounds	Provides nursery areas	Provides refuge from predation	Provides substrate for attachment	Supports a complex trophic structure	Supports biomass production	Supports biodiversity	Affects transport of suspended/dissolved material	Alters turbidity	Modifies water temperature	Provides temporary floodwater storage	Reduces erosion potential	Reduces wave energy	Modifies chemical water quality	Modifies dissolved oxygen	Supports nutrient cycling
Hydrological (cont.)																				
Chemical (cont.)																				
Silicon	◆									◆								◆		
Toxics				◆	◆	◆												◆		
Soil/Sediment																				
Physical																				
Basin elevations				◆	◆	◆	◆	◆			◆	◆		◆	◆					
Bulk density																				◆
Depth of mottling															◆					◆
Geomorphology (slope, basin cross section)				◆	◆	◆	◆	◆			◆	◆	◆	◆	◆	◆		◆	◆	
Moisture levels and drainage											◆				◆					◆
Sediment grain size (OM[8]/sand/silt/clay/gravel/cobble)								◆		◆		◆	◆			◆	◆	◆	◆	◆
Sedimentation rate and quality											◆	◆	◆			◆				
Chemical																				
Organic content in sediment					◆				◆	◆	◆	◆	◆					◆	◆	◆
Pore water nitrogen and phosphorus										◆								◆		◆
Pore water salinity (in tidal areas)											◆								◆	
Redox potential																		◆		◆

[8] Organic matter

◆ = a pairing between a habitat characteristic and a measured parameter

Matrix C: Restoration Monitoring Parameters by Habitats

Habitats

Structural Parameters to Monitor	Water Column	Rock Bottom	Coral Reef	Oyster Reef	Soft Bottom	Kelp and Macroalgae	Rocky Shore	Soft Shore	SAV	Marsh	Mangroves	Deepwater Swamps	Riverine Forests
Geographical													
Acreage of habitat type	●	●	●	●	●	●	●	●	●	●	●	●	●
Biological													
Plants													
Species, composition, and % cover of:													
Algae		❍	❍	❍		●	●	●	❍		❍		
Epiphytes			●		❍	❍	●		❍		❍		
Herbaceous vascular							●	●	●	●	❍	❍	❍
Woody											●	●	●
Basal area												❍	❍
Canopy extent and structure						❍			❍		❍	❍	❍
Interspersion of habitat types						●			❍	●			
Phytoplankton diversity and abundance	❍	❍		❍									
Plant height						❍			❍	❍	❍	❍	❍
Seedling survival						❍			❍	❍	❍	●	●
Stem density									❍	❍	❍	●	●
Woody debris (root masses, stumps, logs)												❍	❍
Animals													
Vertical relief			●	●									
Hydrological													
Physical													
Chlorophyll concentration	●				❍			❍					
PAR	❍					●			●				
Secchi disc depth	❍					●			●				
Shear force at sediment surface	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍			
Sheet flow										❍		●	
Temperature	❍	❍	●			●			❍		❍	❍	❍
Temporary water													❍
Upstream land use	●		❍	❍					❍	❍	●	●	●
Water column current velocity	❍	❍		❍	●	●	❍		●				
Water level fluctuation over time	●	●		●		❍	●	●	●	●	●	●	●
Chemical													
Dissolved oxygen	●			❍	❍	❍			❍				
Groundwater indicator chemicals	❍								❍	❍			❍
Nitrogen and phosphorus	❍		❍	❍	❍				❍	❍	❍		❍
pH	❍			❍		❍				❍			
Salinity (in tidal areas)	●	●		●	●	❍	❍	❍	●	●	●	❍	❍
Silicon	❍												
Toxics	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Soil/Sediment													
Physical													
Basin elevations		❍	❍		❍		❍	❍	❍	❍		❍	❍
Bulk density										❍		❍	❍
Depth of mottling													❍
Geomorphology (slope, basin cross section)		●	●	●	●	●	●	●	●	●	●	●	●
Moisture levels and drainage												❍	❍

● Represents a parameter that is recommended for measurement in most restoration monitoring projects

❍ Represents a parameter that might be useful to monitor depending on the goals of the project but is not considered critical for all monitoring programs

Matrix C: Restoration Monitoring Parameters by Habitats (cont.)

Structural Parameters to Monitor (cont.)	Water Column	Rock Bottom	Coral Reef	Oyster Reef	Soft Bottom	Kelp and Macroalgae	Rocky Shore	Soft Shore	SAV	Marsh	Mangroves	Deepwater Swamps	Riverine Forests
Soil/Sediment													
Physical													
Organic content		❍		❍	●	❍	❍	●	❍	●	❍	❍	❍
Percent sand, silt, and clay		❍			●	❍	●	●	❍	❍	❍	❍	❍
Sedimentation rate and quality		❍	❍	❍	●		❍	❍	❍	●	❍	❍	❍
Chemical													
Pore water nitrogen and phosphorus		❍		❍	❍	❍		❍	❍	❍			❍
Pore water salinity (in tidal areas)										●		❍	
Redox potential									❍	❍		❍	
Functional Parameters to Monitor													
Geographical													
Acreage of habitat types	●	●	●	●	●	●	●	●	●	●	●	●	●
Biological													
Plants													
Species, composition, and % cover of:													
Algae		❍	❍	❍		●	❍	❍	❍		❍		
Epiphytes			●		❍	❍	❍		❍		❍		
Herbaceous vascular							❍	❍	●	●	❍	❍	❍
Invasives		❍			❍		❍	❍	❍	❍	❍	❍	❍
Woody											●	●	●
Basal area												❍	❍
Canopy extent and structure						❍			❍			❍	❍
Interspersion of habitat types	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Litter fall											❍	❍	❍
Mast/seed production													❍
Nutrient levels in algal tissues (N and P)	❍		❍										
Phytoplankton diversity and abundance	❍	❍		❍									
Plant health (herbivory damage, disease)		❍			❍	❍	❍	❍	❍	❍	❍	❍	❍
Plant height						❍			❍	❍		❍	❍
Plant weight (above/ below ground parts)						❍			❍	❍			
Rate of canopy closure						❍			❍		❍	❍	❍
Seedling survival						❍			❍	❍	❍	●	●
Stem density						❍			❍	❍		❍	❍
Woody debris (root masses, stumps, logs)												❍	❍
Animals													
Species, composition, and abundance of:													
Amphibians										❍	❍		❍
Birds		❍		❍		❍	●	●	❍	❍	●	❍	❍
Fish	❍	●	●	❍	❍	❍	❍	❍	❍	❍	❍	❍	
Invasives	❍	❍	❍	●	❍		❍	❍	❍	❍		❍	
Invertebrate	❍	●	●	❍	●	❍	●	●	❍	❍	❍	❍	❍
Mammals										❍	❍	❍	❍
Reptiles										❍	❍	❍	❍

● Represents a parameter that is recommended for measurement in most restoration monitoring projects

❍ Represents a parameter that might be useful to monitor depending on the goals of the project but is not considered critical for all monitoring programs

Matrix C: Restoration Monitoring Parameters by Habitats (cont.)

Habitats

Functional Parameters to Monitor (cont.)	Water Column	Rock Bottom	Coral Reef	Oyster Reef	Soft Bottom	Kelp and Macroalgae	Rocky Shore	Soft Shore	SAV	Marsh	Mangroves	Deepwater Swamps	Riverine Forests
Biological (cont.)													
Animals (cont.)													
Animal health (disease)				●									
Coral growth rate			❍										
Coral recruitment, and survival			❍										
Fecal coliforms	❍				❍								
Grazer density			❍				❍						
Vertical relief of reef			●	●									
Hydrological													
Physical													
Fetch	❍						❍	❍	❍	❍	❍	❍	
PAR				●		●			●	❍	❍	❍	❍
Secchi disc depth	❍			●		●			●	❍	❍	❍	❍
Shear force at sediment surface					❍			❍	❍	❍			
Sheet flow										❍		❍	❍
Temperature									❍			❍	❍
Temporary water													❍
Trash	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Upstream land use	●		❍	❍					❍	❍		●	●
Water column current velocity	❍		❍	❍		❍	❍		❍		❍	❍	
Water level fluctuation over time	●	●		●		❍	●	●	●	●	●	●	●
Chemical													
Chlorophyll concentration	●				❍			❍					
Dissolved oxygen	●			❍	❍	❍			❍				
Nitrogen and phosphorus	❍			❍	❍				❍	❍	❍	❍	❍
Salinity (in tidal areas)	❍								❍	❍		❍	
Silicon	❍												
Toxics	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Soil/Sediment													
Physical													
Basin elevations			❍	❍	❍				❍	❍		❍	
Bulk density										❍		❍	❍
Depth of mottling													❍
Geomorphology (slope, basin cross section)		●	●	●	●	●	●	●	●	●	●	●	●
Moisture levels and drainage												❍	❍
Sediment grain size (OM/sand/silt/clay/gravel/cobble)		❍	❍	❍	●	❍	❍	❍	❍	❍	❍	❍	❍
Sedimentation rate and quality		❍	❍	❍	●		❍	❍	❍	❍	❍	❍	❍
Trash		❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Chemical													
Organic content in sediment					❍			❍	❍	❍		❍	❍
Pore water nitrogen and phosphorus										❍		❍	❍
Pore water salinity (in tidal areas)										❍		❍	
Redox potential										❍		❍	❍

● Represents a parameter that is recommended for measurement in most restoration monitoring projects

❍ Represents a parameter that might be useful to monitor depending on the goals of the project but is not considered critical for all monitoring programs

APPENDIX III: GLOSSARY

Abiotic — non-living

Aerobic — (of an organism or tissue) requiring air for life; pertaining to or caused by the presence of oxygen

Algae — non-vascular plants that are very small; algae are the main producers of food and oxygen in aquatic environments

Alluvial plain — the floodplain of a river, where the soils are deposited by the overflowing river

Alluvium — any sediment deposited by flowing water, as in a riverbed, floodplain, or delta

Alternate hypothesis — a statistical hypothesis that disagrees with the tested hypothesis, e.g., these two wetlands do not have the same vegetation community

Anaerobic — living in the absence of oxygen; pertaining to or caused by the absence of oxygen

Anoxic — without oxygen

Anthropogenic — caused by humans; often used when referring to human induced environmental degradation

Aquatic — living or growing in or on water

Attenuation — to lessen the amount, force, magnitude, or value of

Backwater — a body of water in which the flow is slowed or turned back by an obstruction such as a bridge or dam, an opposing current, or the movement of the tide

Baseline measurements — a set of measurements taken to assess the current or pre-restoration condition of a community or ecosystem

Beach seine — a short (typically 20 m or less) fine mesh catch net that can be pulled through shallow water on to beach areas by hand

Benthic — on the bottom or near the bottom of streams, lakes, or oceans

Biogenic — produced by living organisms

Biomass — the amount of living matter, in the form of organisms, both plants and animals, present in a particular habitat, usually expressed as weight-per-unit area

Blackwater streams — streams that do not carry sediment, but are dark in color due to the tannins dissolved in them from flowing through peat-based areas

Brackish — water with a salinity intermediate between seawater and freshwater, often referred to as oligohaline (salinity 0.5 to 5.0 ppt). Interlacing or tangled network of several small branching and reuniting shallow channels are also often present.

Brackish marsh — marsh areas containing a mixture of salt and fresh water; however, the salinity level is less than seawater

Breeder trap — a small box shaped trap containing a funneled entrance and constructed of clear plexiglass, that is set on the sediment surface to catch fry and small sized fish species

Calcareous — sediment/soil formed of calcium carbonate or magnesium carbonate due to biological deposition or inorganic precipitation

Catchment — the land area drained by a river or stream; also known as “watershed” or “drainage basin”; the area is determined by topography that divides drainage between watersheds

Coastal habitat restoration — the process of reestablishing a self-sustaining habitat in coastal areas that in time can come to closely resemble a natural condition in terms of structure and function

Coastal habitat restoration monitoring — the systematic collection and analysis of data that provides information useful for measuring coastal habitat restoration project performance

Community — all the groups of organisms living together in the same area, usually interacting or depending on each other for existence; all the living organisms present in an ecosystem

Coral reefs — highly diverse ecosystems, found in warm, clear, shallow waters of tropical oceans worldwide. They are composed of marine polyps that secrete a hard calcium carbonate skeleton, which serves as a base or substrate for the colony.

Coralline algae — algae that contains a coral-like, calcareous outer covering

Cost estimate — estimates on costs of planning and carrying out a project. Examples of items that may be included in a cost estimate for a monitoring plan may be personnel, authority to provide easements and rights-of-way, maintenance, labor, and equipment.

Deepwater swamps — forested wetlands that develop along edges of lakes, alluvial river swamps, in slow-flowing strands, and in large, coastal-wetland complexes. They can be found along the Atlantic and Gulf Coasts and throughout the Mississippi River valley. They are distinguished from other forested habitats by the tolerance of the dominant vegetation to prolonged flooding.

Demersal — bottom-feeding or bottom-dwelling fish, crustaceans, and other free moving organisms

Desiccation – process of extracting moisture

Detritivorous — the practice of eating primarily detritus

Detritus — fine particles of decaying organic and inorganic matter formed by excrement and by plant and animal remains; may be suspended in water or accumulated on the bottom of a water body

Diatoms — any of a class (Bacillariophyceae) of minute planktonic unicellular or colonial algae with silica-based skeletons

Dissolved oxygen — oxygen dissolved in water and available to aquatic organisms; one of the most important indicators of the condition of a water body; concentrations below 5 mg/l are stressful and may be lethal to many fish and other species

Dominant species — a plant species that exerts a controlling influence on or defines the character of a community

Downwelling — the process of build-up and sinking of warm surface waters along coastlines

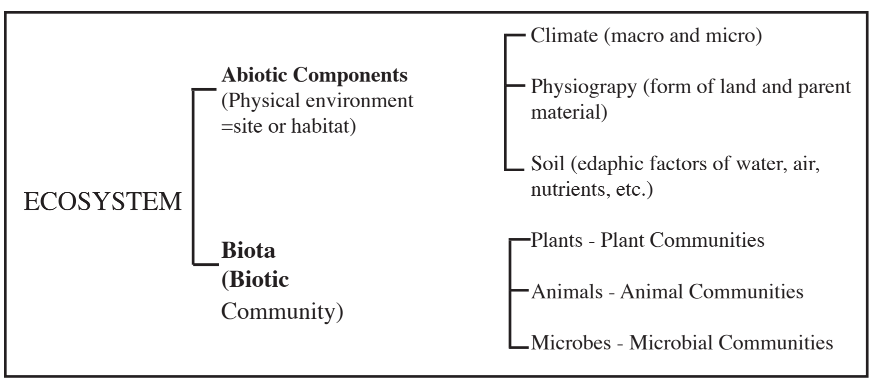
Drop sampler — a shallow water sampling device, typically 1 – 2 m in diameter used to collect fish and decapods via a drop in the water from a boom or support platform, and subsequent collection using small seines or suction pumping the water within the trap

Duration — a span or interval of time

Ebb — a period of fading away; low tide

Echinoderms — any of a phylum (Echinodermata) of radially symmetrical primitive marine animals including the starfishes, sea urchins, and related forms

Ecosystem — a volume of land and air including all the biotic and abiotic components (*Graphic courtesy of B. Barnes, University of Michigan*)



Emergent plants — aquatic plants with roots and part of the stem below water level, but the rest of the plant is above water; e.g., cattails and bulrushes

Ephemeral — lasting a very short time

Epifaunal — animals living on the surface of the sediment or other substrate such as debris

Epiphytes — plants that grow on another plant or object upon which it depends for mechanical support but not as a source of nutrients; i.e. not parasitic

Estuary — a part of a river, stream, or other body of water that has at least a seasonal connection with the open sea or Great Lakes and where the seawater or Great Lakes water mixes

with the surface or subsurface water flow, regardless of the presence of man-made structures or obstructions

Eulittoral — refers to that part of the shoreline that is situated between the highest and lowest seasonal water levels

Eutrophic — designating a body of water in which the increase of mineral and organic nutrients has reduced the dissolved oxygen, producing an environment that favors plant over animal life

Eutrophication — a natural process, that can be accelerated by human activities, whereby the concentration of nutrients in rivers, estuaries, and other bodies of water increases; over time this can result in anaerobic (lack of oxygen) conditions in the water column; the increase of nutrients stimulates algae "blooms" as the algae decays and dies, the availability of dissolved oxygen is reduced; as a result, creatures living in the water accustomed to aerobic conditions perish

Evapotranspiration — the combination of water that is evaporated and transpired by plants as a part of their metabolic processes

Exotic species — plants or animals not native to the area

Fauna — animals collectively, especially the animals of a particular region or time

Fecal coliforms — any of several bacilli, especially of the genera *Escherichia*, found in the intestines of animals. Their presence in water suggests contamination with sewage of feces, which in turn could mean that disease-causing bacteria or viruses are present. Fecal coliform bacteria are used to indicate possible sewage contamination. Fecal coliform bacteria are not harmful themselves, but indicate the possible presence of disease-causing bacteria, viruses, and protozoans that live in human and animal digestive systems. In addition to the possible health risks associated with them, the bacteria can also cause cloudy water, unpleasant odors, and decrease dissolved oxygen in the water.

Fetch — the distance along open water or land over which the wind blows

Flooding regime — pattern of flooding over time

Floodplain — a strip of relatively flat land bordering a stream channel that may be overflowed at times of high water; the amount of land inundated during a flood is relative to the severity of a flood event

Flora — plants collectively, especially the plants of a particular region or time

Fluvial — of, relating to, or living in a stream or river

Food chain — interrelations of organisms that feed upon each other, transferring energy and nutrients; typically solar energy is processed by plants who are eaten by herbivores which in turn are eaten by carnivores: sun –> grass –> mouse –> owl

Food webs — the combined food chains of a community or ecosystem

Frequency — how often something happens

Fronds — leaf-like structures of kelp plants

Function — refers to how wetlands and riparian areas work – the physical, chemical, and biological processes that occur in these settings, which are a result of their physical and biological structure regardless of any human benefit

Functional habitat characteristics — parameters that describe what ecological service a habitat provides and may be used as a measure to determine how well a particular place performs a specific function

Fyke net — a collection net which is staked to the sediment aurface and constructed of small mesh that uses tidal fluctuation or current to entrain fish and decapods via wings that act to funnel the catch into a box like mouth containing a series of chambers and partitions used to retain the catch

Gastropods — any of a large class (Gastropoda) of mollusks (as snails and slugs) usually with a single shell or no shell and a distinct head bearing sensory organs

Geomorphic — pertaining to the form of the Earth or its surface features

Geomorphology — the science that treats the general configuration of the Earth's surface; the description of landforms

Habitat — the sum total of all the living and non-living factors that surround and potentially influence an organism; a particular organism's environment

Hectare – the area of a square 100 m on each side: approximately 107,600 square feet; 12,000 square yards; or 2.5 acres

Herbivory — the act of feeding on plants

Holdfasts — a part by which a plant clings to a surface

Hydric soil — a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation. Field indicators of hydric soils can include a thick layer of decomposing plant material on the surface; the odor of rotten eggs (sulfur); and colors of bluish–gray, gray, black, with occasional contrasting brighter spots of color

Hydrodynamics — the motion of water that generally corresponds to its capacity to do work such as transport sediments, erode soils, flush pore waters in sediments, fluctuate vertically, etc. Motions can vary within each of three flow types: primarily vertical, primarily bidirectional and horizontal, and primarily unidirectional and horizontal. Vertical

fluxes are driven by evapotranspiration and precipitation. Bidirectional flows are driven by astronomic tides and wind-driven seiches. Unidirectional flows are down slope movement that occurs from seepage slopes and on floodplains.

Hydrology — the study of the cycle of water movement on, over and through the earth's surface; the science dealing with the properties, distribution, and circulation of water

Hydroperiod — depth, duration, seasonality, and frequency of flooding

Hydrostatic pressure — the pressure water exerts at any given point when a body of water is in a still motion

Hypersaline — extremely saline, generally over 30 ppt salinity (average ocean water salinity)

Hypoxic — waters with dissolved oxygen less than 2 mg/L, the point at which most aquatic life dies

Infauna — plants that live in the sediment

Interspersion — scattered or distributed at regular intervals

Interstices — a space that intervenes between things; especially one between closely spaced things

Intertidal — an area that is alternately flooded and exposed by tides

Intralittoral — a sub-area of the sublittoral zone where upward-facing rocks are dominated by algae, mainly kelp

Invasive species — a species that does not naturally occur in a specific area and whose introduction is likely to cause economic or environmental harm

Invertebrate — an animal with no backbone or spinal column; invertebrates include 95% of the animal kingdom

Irregularly exposed — refers to coastal wetlands with substrate exposed by tides less frequently than daily

Lacunar — a small cavity, pit, or discontinuity

Lacustrine — pertaining to, produced by, or formed in a lake

Lagoons — a shallow stretch of seawater (or lake water) near or open to the sea (or lake) and partly or completely separated from it by a low, narrow, elongate strip of land

Line transect — a straight line is laid out across a project area. Samples or measurements are taken at specific, predetermined locations along this straight line

Littoral — refers to the shallow water zone (less than 2 m deep) at the end of a water body, commonly seen in lakes or ponds

Macroalgae — relatively shallow (less than 50 m deep) subtidal algal communities dominated by very large brown algae. Kelp and other macroalgae grow on hard or consolidated substrates forming extensive three-dimensional structures that support a diversity of other plants and animals.

Macrofauna — animals large enough to be seen with the naked eye, typically exceeding 1 mm in length or that will not pass through a 1 mm sieve

Macroinvertebrate — animals without backbones that can be seen with the naked eye (caught with a 1 to 2 mm mesh net); includes insects, crayfish, snails, mussels, clams, fairy shrimp, etc.

Macrophytes — plant species that are observed with the naked eye, e.g., vascular plants

Mangroves — swamps dominated by shrubs that live between the sea and the land in areas that are inundated by tides. Mangroves thrive along protected shores with fine-grained sediments where the mean temperature during the coldest month is greater than 20° C, limiting their northern distribution.

Marine polyps — the small living units of a coral, responsible for secreting calcium carbonate maintaining coral reef shape

Marshes (marine and freshwater) — transitional habitats between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water tidally or seasonally. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Mast — the nuts of forest trees accumulated on the ground

Meiofauna — diverse microorganisms that are approximately between .042 mm and 1 mm in size

Metadata — data that describes or provides background information on other data

Microfauna — animals that are very small and best identified with the use of a microscope, e.g., protozoans and nematodes

Microinvertebrates — invertebrates so small they can only be observed with a microscope

Micro-topography — very slight changes in the configuration of a surface including its relief and the position of its natural and man-made features

Migratory — a creature that moves from one region to another when the seasons change

Morphology — the study of structure and form, either of biological organisms or features of the earth surface

Mottling — contrasting spots of bright colors in a soil; an indication of some oxidation or ground water level fluctuation

Mudflat — bare, flat bottoms of lakes, rivers and ponds, or coastal waters, largely filled with organic deposits, freshly exposed by a lowering of the water level; a broad expanse of muddy substrate commonly occurring in estuaries and bays

Nanoplankton — plankton of minute size, generally size range is from 2 - 20 micrometers

Native — an animal or plant that lives or grows naturally in a certain region

Nearshore — nearshore waters beginning at the shoreline or the lakeward edge of the coastal wetlands and extending offshore to the deepest lakebed contour where the thermocline typically intersects with the lakebed in late summer or early fall

Non-point source — the origin of any water-carried material from a broad area rather than from a discrete point, e.g., runoff from agricultural fields

Nuisance species — undesirable plants and animals, commonly exotic species

Null hypothesis — a statistical hypothesis the truth of which is to be investigated by sampling, e.g., these two wetlands have the same vegetation community

Nutria — a large South American semi-aquatic rodent (*Myocastor coypus*) with webbed hind feet that has been introduced into parts of Europe, Asia, and North America

Nutrient — any inorganic or organic compound that provides the nourishment needed for the survival of an organism

Nutrient cycling — the transformation of nutrients from one chemical form to another by physical, chemical, and biological processes as they are transferred from one trophic level to another and returned to the abiotic environment

Oligotrophic — a water body that is poor in nutrients, refers mainly to lakes, ponds, and some wetlands

One-hundred year flood — refers to the floodwater levels that would occur once in 100 years, or as a 1.0 percent probability per year

Organic — containing carbon, but possibly also containing hydrogen, oxygen, chlorine, nitrogen, and other elements

Organic material — anything that is living or was living; in soil it is usually made up of nuts, leaves, twigs, bark, etc.

Osmotic stress — water stress due to differences in salinity between an organism and its aquatic environment

Overstory — trees that tower above the surrounding canopy

Oyster beds — dense, highly structured communities of individual oysters growing on the shells of dead oysters

Palustrine — nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5%

Pelagic — pertaining to, or living in open water column

pH — a measure of the acidity (less than 7) or alkalinity (greater than 7) of a solution; a pH of 7 is considered neutral

Physiographic setting — the location in a landscape, such as stream headwater locations, valley bottom depression, and coastal position, similar to geomorphic setting

Physiography — a description of the surface features of the Earth, with an emphasis on the mode or origin

Phytoplankton — microscopic floating plants, mainly algae that are suspended in the water column and are transported by wave currents

Piscivorous — feeding on fish

Pit trap — a collection method that uses shallow depressions dug into the sediment surface that are lined with a non porous water retaining container, to collect select fish and decapod species that use depression on the sediment surface as refuge habitats during low tide

Planktivorous — eating primarily plankton

Plankton — plants and animals, generally microscopic and float or drift in fresh or saltwater

Pneumatocysts — known as gas bladders or floaters that help a plant stay afloat, e.g., bladders seen in the brown alga *Macrocystis*

Pneumatophores — specialized roots formed by several species of plants occurring in frequently inundated habitats. The root is erect and protrudes above the soil surface.

Pop net — a shallow water sampling gear typically 1 – 2 m in diameter composed of fine mesh that is used to collect fish and decapods. The pop net is attached to the sediment surface, and after some time a connected float collar is released from the sediment surface to encompass the whole of the water column in the area of the net. Catch within the pop net is then collected via seines or suction pumping the water within the trap.

Population — a collection of individuals of one species or mixed species making up the residents of a particular area

ppt — parts per thousand, the salinity of ocean water is approximately 35 ppt

Prop roots — long root structures that extend midway from the trunk and arch downward creating tangled branching roots above and below the water's surface, such as in the mangrove *Rhizophora*

Propagules — a structure (such as a cutting, a seed, or a spore) from which a new plant can grow

Pseudofeces — material expelled by the oyster without having gone through the animal's digestive system

Quality assurance/quality control plan — a detailed plan that describes the means of data collection, handling, formatting, storage, and public accessibility for a project

Rebar — also called reinforcing bar; a steel rod with ridges for use in reinforced concrete

Receiving water bodies — lakes, estuaries, or other surface waters that have flowing water delivered to them

Redox potential — oxygen-reduction potential, often used to quantify the degree of electrochemical reduction of wetland soils under anoxic conditions

Reference condition — set of selected measurements or conditions to which a restoration project will be compared, may be relatively pristine or very degraded

Reference site — a site that is representative of the expected ecological conditions and integrity of other sites of the same type and region

Regime — a regular pattern of occurrence or action

Restoration — the process of reestablishing a self-sustaining habitat that in time may come to closely resemble a natural condition in terms of structure and function

Restoration monitoring — the systematic collection and analysis of data that provides information useful for measuring restoration project performance at a variety of scales (locally, regionally, and nationally)

Rhizome — somewhat elongate usually horizontal subterranean plant stem that is often thickened by deposits of reserve food material, produces shoots above and roots below, and is distinguished from a true root in possessing buds, nodes, and usually scale-like leaves

Riparian — a form of wetland transition comprised of multiple habitats and located between permanently saturated wetland and upland habitats. These areas exhibit vegetation or physical characteristics reflective of permanent surface of subsurface water influence. Lands along, adjacent to, or contiguous with perennially and intermittently flowing rivers and streams, glacial potholes, and the shores of lakes and reservoirs with stable water levels are typically riparian areas. Excluded are such sites as ephemeral streams or washes that do not exhibit the presence of vegetation dependent upon free water in the soil.

Riverine — associated with rivers

Riverine forests — forests found along sluggish streams, drainage depressions, and in large alluvial floodplains. Although associated with deepwater swamps in the southeastern United

States, riverine forests are found throughout the United States and are not subject to prolonged flooding.

Rock bottom — all wetlands and deepwater habitats with substrates having an areal cover of stones, boulders, or bedrock 75% or greater, and vegetative cover of less than 30%

Rocky shoreline — extensive littoral habitats on wave-exposed coasts, the substrate is composed of boulders, rocks, or cobble

Salinity — the concentration of dissolved salts in a body of water, commonly expressed as parts per thousand

Salt pans — an undrained natural depression in which water gathers and leaves a deposit of salt upon evaporation

Sampling designs — the procedure for selecting samples from a population and the subsequent statistical analysis

SAV (marine, brackish, and freshwater) — flowering plants that grow on soft sediments in sheltered shallow waters of estuaries, bays, lagoons, and lakes. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Seasonality — the change in natural cycles over time, such as lunar cycles and flooding cycles; changes from one season to the next

Seiches — a sudden oscillation of the water surface in a moderate-size body of water, caused by wind

Senescence — the life stage in a plant or plant part (such as a leaf) from full maturity to death, also applies to winter dormancy

Sessile — permanently attached or established, not free to move about

Socioeconomic monitoring — tracking of key indicators that characterize the economic and social state of a human community

Soft bottom — loose, unconsolidated substrate characterized by fine to coarse-grained sediment

Soft shoreline — sand beaches and muddy shores; stretches of land covered by loose material, exposed to and shaped by waves and/or wind.

Statistical hypothesis — a statement about the population or populations being sampled, or occasionally a statement about the sampling procedure

Statistical protocol — a method of analyzing a collection of observed values in order to make an inference about one or more characteristic of a population or unit

Strands — a diffuse freshwater stream flowing through a shallow vegetated depression on a gentle slope

Stratified random sampling — a population is divided into subgroups that are homogeneous. Random samples are then taken within each subgroup, assuring that key subgroups within a population are sampled, particularly those in the minority. This type of sampling can be done for populations or for areas.

Structural habitat characteristics — characteristics that define the physical composition of a habitat, the functions an ecosystem can perform are often dependent upon its structure

Subtidal — continuously submerged areas affected by ocean tides

Supralittoral region — an area above the high tide mark receiving splashing from waves

Taxa — a grouping of organisms given a formal taxonomic name such as species, genus, family, etc. (singular form is taxon)

Tested hypothesis — a statistical hypothesis the truth of which is to be investigated by sampling, sometimes called the null hypothesis

Thermocline — a horizontal region in a thermally stratified body of water than separates warmer oxygen-rich surface water from cold oxygen-poor deep water

Tide — the rhythmic, alternate rise and fall of the surface (or water level) of the ocean, and connected bodies of water, occurring twice a day over most of the earth, resulting from the gravitational attraction of the moon, and to a lesser degree, the sun

Time series — an ordered sequence of values of a certain variable that are equally spaced over time

Time series analysis — looking for patterns such as seasonal variations or impacts of events in data sets whose measurements are collected at equally spaced intervals over time

Topography — the general configuration of a land surface or any part of the earth's surface, including its relief and the position of its natural and man-made features

Transient — passing through or by a place with only a brief stay or sojourn

Trophic — refers to food, nutrition, or growth state

Trophic level — a group of organisms united by obtaining their energy from the same part of the food web of a biological community

Unconsolidated — loosely arranged

Understory — trees and tall bushes that are completely submerged under the canopy

Viviparous — producing living young instead of eggs from within the body in the manner of nearly all mammals, many reptiles, and a few fishes; germinating while still attached to the parent plant

Water column — a conceptual volume of water extending from the water surface down to, but not including the substrate, found in marine, estuarine, river, and lacustrine systems

Watershed — surface drainage area that contributes water to a lake, river, or other body of water; the land area drained by a river or stream

Zonation — a state or condition that is marked with bands of color, texture, or different species

Zooplankton — free-floating animals that drift in the water, ranging in size from microscopic organisms to larger animals such as jellyfish

APPENDIX IV: ACKNOWLEDGMENTS

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